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Delivering a sustainable future for offices in Greece in the context of climate change: the case-study of a public office building

by

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I would like to thank my parents and my uncle who are responsible for what I am today since they have always been my physical and mental pilots.

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Abstract

The 1990's has been the warmest decade globally leading to a dramatic climate change due to the greenhouse effect and the consequent ***global warming***. Allowing this trend to continue the planet is going to face a catastrophic climate change without precedent with various impacts. One of the most significant aims in the combat against climate change is the reduction of ***carbon dioxide*** and other ***greenhouse gases emissions*** that are responsible for global warming. Under the **Kyoto *protocol***, the developed countries need to reduce their GHGs emissions to 1990 levels by 2012.

Energy consumption for building-related services in the ***European Union*** accounts for approximately 50% of the total energy consumption and the resulting CO_2 emissions (Richarz et al 2007). Hence, at first sight the best policy for a decrease is by improving the ***energy performance*** of new and existing buildings. The question to be solved, however, is which improvements at buildings could reduce ***energy consumption*** and accordingly CO_2 emissions?

In this context, the analysis of the energy consumption and the respective carbon emissions over a public large-scale existing office building in Greece can result in a comprehensive understanding of how energy efficiency-upgrades can be critical when combating climate change. This analysis is made using thermal analysis software and extracting results about energy consumption that can be compared to the real data collected from the Building Energy Management System. Afterwards, potential improvements in the building envelope in terms of a more efficient control of solar gains are tested on the model and finally, photovoltaics are applied in order to generate zero-carbon electricity.

The energy-efficiency upgrades suggested have achieved a total reduction in energy used for heating and cooling by 11.9%, with the reduction in cooling far exceeding the respective reduction in heating. Consequently, 193 MWh that are equivalent to 117 tons of CO_2 are saved annually. As far as the application of photovoltaics is concerned, the roof installation can generate electricity equal to 10% of the annual building requirements in energy.

In general, a successful energy-efficiency upgrade of an existing office building relies on the interconnections of three levels of improvements; passive design techniques, systems efficiency and application of photovoltaics. Finally, the impact of energy-efficiency upgrade of office buildings in Greece can be very positive. However, appropriate legislation needs to come in force urgently in order to make energy-efficiency upgrades at existing buildings compulsory in an attempt to reduce carbon emissions.

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Chapter 1: Introduction

1.1. Climate change & global warming

The 1990's has been the warmest decade globally leading to a dramatic climate change due to the greenhouse effect and the consequent global warming. Climate change is probably the greatest long term challenge facing the human race (DBERR 2008). It has already been threatening the sustainable future of the Earth and has led us into an era in which global warming is taking place at a faster rate than previously believed (Sassi 2006) with various impacts on the ecosystem.

Figure 1: irrational industrialization leads to global warming

Allowing this trend to continue the planet is going to face a catastrophic climate change without precedent with various impacts. The response to this trend is the most crucial challenge governments are facing in the 21st century (RICS 2008). Now there is a widespread agreement, according to Smith (2005), that climate change is 90% certain to be due to human activity mainly through the burning of fossil-based energy.

And at this point, panic over global warming has begun and it faces two different sources of anxiety; the first resolves around the familiar struggle for affordable fuel. The second, however, concerns a more sustainable approach of the issue; the battle to combat climate change by reducing CO_2 emissions (Rachman 2007). One of the most significant aims is the reduction of ***carbon dioxide (CO_2)*** and other ***greenhouse gases (GHG)*** emissions that are responsible for the global warming. Under the ***Kyoto protocol***, the developed countries need to reduce their GHGs emissions to 1990 levels by the year 2012.

In this context, it is crucial to set the principles of the new-era sustainable cities. By the end of the 21st century 70-80% of the world's population will live in concentrated urban areas (Battle & McCarthy 2001). The common dilemma is how to best manage the interconnections between ecological conditions and balances, on the one hand, and social needs and priorities, on the other (Scott 1998). At this point, it would be useful to refer to the main aspects of an urban entity; a city metabolism is comprised of six cycles: ***transportation, energy, water, microclimate, landscape*** and ***ecology***. Each one has their own individual patterns but in some way all affect one another. As a result, modern metropolitan cities play a significant role in the phenomenon of climate change and their rational or irrational development will be the regulator of the gradation of this phenomenon.

And as urban environments consist of buildings it is important to mention that energy consumption for building-related services in the ***European Union (EU)*** accounts for approximately 50% of the total energy consumption and the resulting CO_2 emissions (Richarz et al 2007). Hence, at first sight the best policy for a decrease in emissions is by improving the energy performance of new and existing buildings. The question to be solved, however, is which improvements at buildings could reduce energy consumption and accordingly CO_2 emissions?

Nearly half of the UK's energy use is accounted for in buildings and approximately one third of this energy is used in non-domestic buildings (Baker & Steemers 2000), which is similar to most EU countries (figure 2). As a result, buildings can be considered as engines for environmental restoration. They can force sustainability in the building sector contributing to the efforts against climate change.

And according to Battle & McCarthy (2001) there are many different definitions of ***sustainability***; to engineers it is to maximize uses of materials, skills and energy for the benefit of mankind. However, architects and society define the benefits (Scott 1998). Architecture has defined the dimensions of sustainability from a variety of perspectives and all of them focus on design that incorporates environmental principles and promotes sustainability.

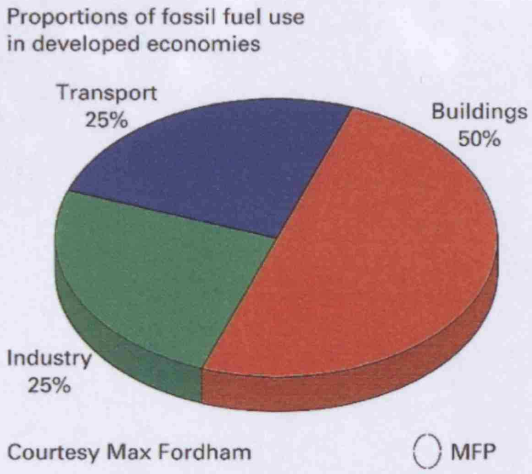


Figure 2: graph showing the relatively large impacts of buildings in the developed world in terms of their emissions of greenhouse gases

1.2. Greece being kicked out of the Kyoto Protocol

The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change that sets binding targets for 37 industrialized countries and the European community for GHG emissions (UNFCCC 2008). These targets refer to a reduction of GHG emissions by average 5% against 1990 levels over the five-year period 2008-2012.

Figure 3: under Kyoto Protocol GHGs emissions must be reduced

However, in this imperative context, Greece has been recently suspended from the United Nations carbon trading in an unprecedented punishment for violating GHGs reporting rules (Jukwey 2008) with various social and environmental impacts on the combat against climate change. Greece's expulsion from the United Nations carbon trading was the result of failing to comply with the commitments it signed on reducing CO_2 emissions and now faces a bill of at least € 225 million by 2010 (Kathimerini 2008). According to the Kyoto protocol, Greece has been allowed to increase carbon emissions by 25% from 1990 to 2010 (figure 4). By the year 2008, however, carbon emissions have already been increased by 25%, far exceeding that target. And by 2010 emissions will have been increased by 38.4%, an excess of 15 million tons of CO_2 emissions.

This fact sets a new context under which instant action must be taken in order to reverse the condition. Greece needs to implement all the appropriate methods that will contribute to the reduction of CO_2 emissions. And since the building sector is responsible for almost half of energy use and the respective GHGs emissions, it is now utmost need to improve the energy performance of buildings and reduce their reliance on energy generated from fossil fuels. Consequently, the enhancement of the energy performance of existing buildings is of major significance because such buildings often lack the appropriate environmental qualities and tend to be large consumers of energy.

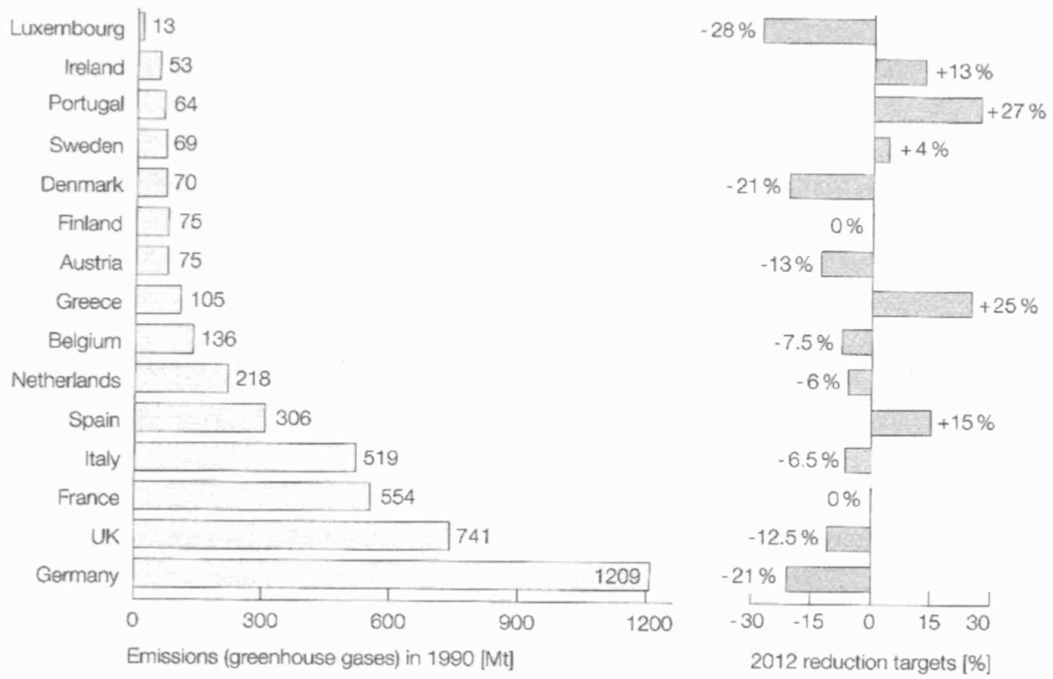


Figure 4: GHGs emissions in 1990 (Mt) and 2012 reduction targets (%)

1.3. Why office buildings?

Office buildings are large consumers of energy in the contemporary urban context. Energy use in offices has risen in recent years because of the growth in information technology, air-conditioning and intensity of use (ECON19 2000). In addition to this, office buildings have traditionally been extravagant users of energy because energy is a relatively minor fraction of the total annual budget. In this context, architects need to play a major role in improving the energy performance of buildings. Architect's primary aim is to design the built environment with respect to the physical environment incorporating occupants' needs and demands whilst maintaining a high-quality result. So, in the new era, the reviewed aim of the architect is to meet the primary aim and maximize comfort for the inhabitants whilst minimizing reliance on fossil-based energy (Smith 2005). In other words, the architect must possess some basic energy performance skills (Richarz et al 2007) in order to correspond to the new commissions.

Energy use in office buildings varies with the type of the building. There are several parameters related to the building characteristics that affect energy consumption. First of all, the standards to which the building and its services are designed along with the potential of ***open-planned offices*** that require more energy for lighting play a significant role in terms of energy use. Additionally, the building quality i.e. the ***efficient design***, the quality of ***construction*** and ***installation*** are very important factors. Finally, energy use in offices is influenced by the occupancy and ***management*** of the building. For instance, the ***occupancy*** hours, the amount of ***equipment*** installed and the effective ***maintenance*** of the building services are some of the factors related to occupancy and management (ECON19 2000).

According to Energy Consumption Guide 19 (2000), energy in office buildings is mainly used for the building services. The major services that are responsible for the energy use are heating, cooling, lighting and office equipment (figure 5).

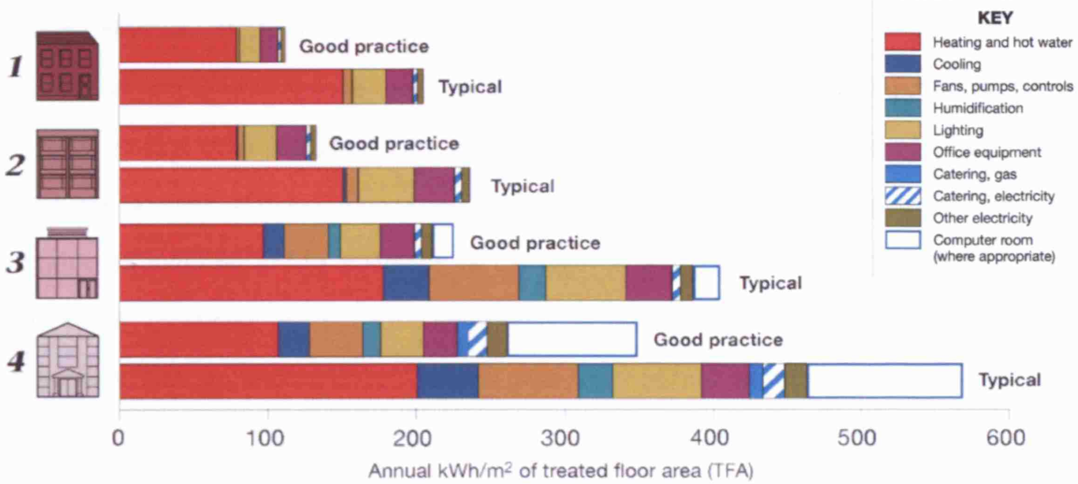


Figure 5: Energy use indices (EUIs) for good practice and typical examples of four office types (1: naturally-ventilated, 2: naturally-ventilated open-plan, 3: air-conditioned standard, 4: air-conditioned prestige)

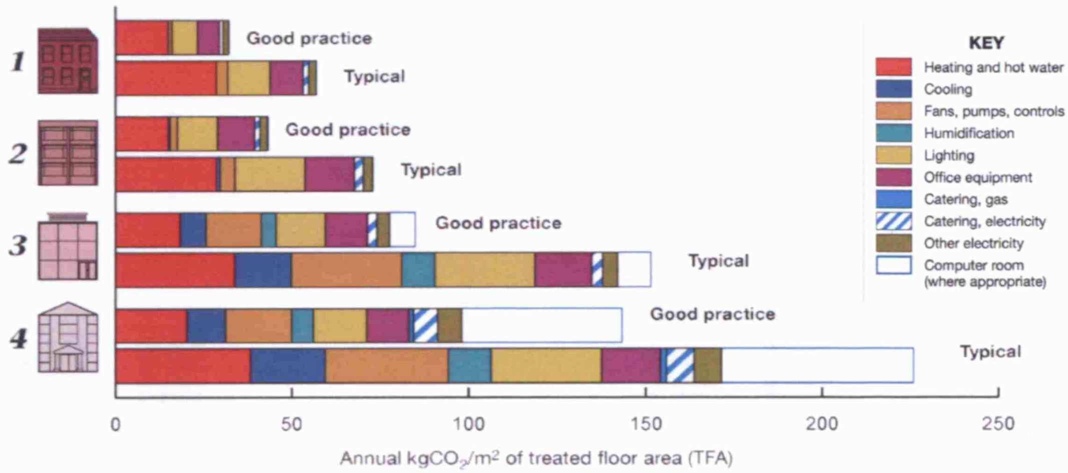


Figure 6: CO_2 emission indices for good practice and typical examples of the four office types

As illustrated on figures 5, 6 the most energy consuming and polluting office building is the air-conditioned, prestige one, whereas the most sustainable appears to be a naturally-ventilated office building. However, focusing on the prestige air-conditioned offices that are more common in countries with hot and dry climate (e.g. Mediterranean countries) it is important to analyze where energy does go. According to figure 5, in such cases the largest portion of energy is used for heating and hot water (200 kWh/m²). At the same time energy used for fans, pumps and controls is almost equal to that used for lighting and approaches 60 kWh/m². Finally, less energy is used for humidification and catering (gas and electricity).

It is obvious that a commitment to bioclimatic architectural design should be implemented in order to reduce energy use in offices. Energy and sustainability is a crucial issue today. And buildings can contribute to promote awareness of sustainability, which ensures a more efficient operation of the building (Sassi 2006). Improving the energy performance of existing office buildings is of major significance when attempting to reduce the impacts of irrational energy use. However, it is important to point out that energy consumption is not an indicator of the degree of comfort in buildings. More complaints associated with comfort conditions relate to air-conditioned buildings that generally consume more energy than non-air-conditioned ones (Baker & Steemers 2000).

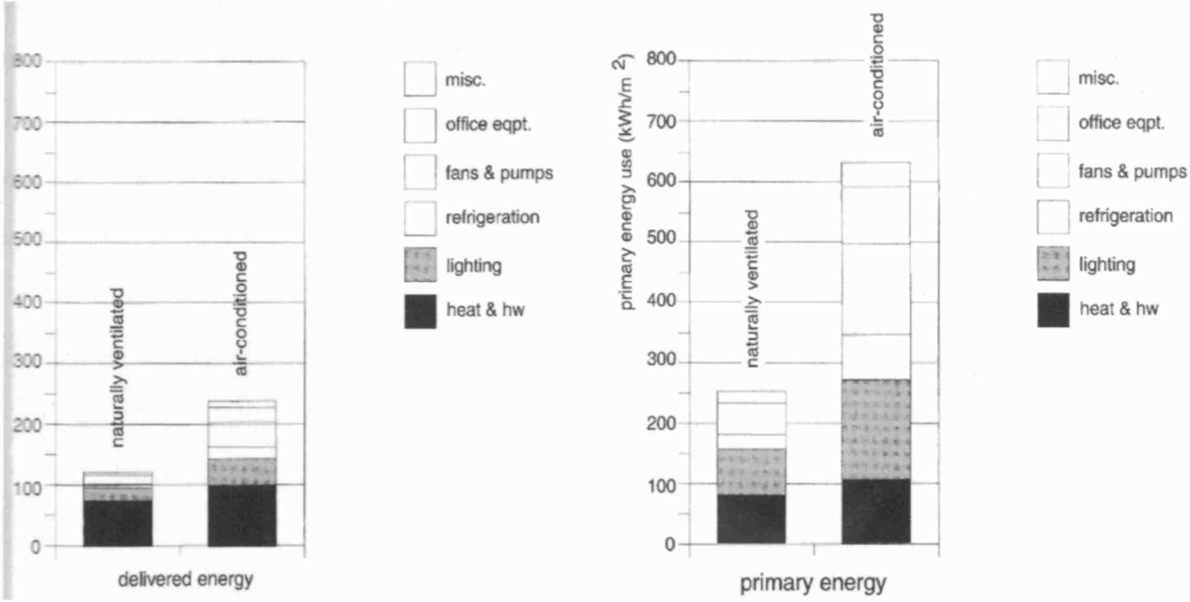


Figure 7: delivered and primary energy use for naturally ventilated and air-conditioned offices in the UK

The factors affecting the energy consumption of a non-domestic building are:

1. *building design*
2. *services design and performance (systems)*
3. *occupant behavior*
4. *presence of a particular activity or process in the building*

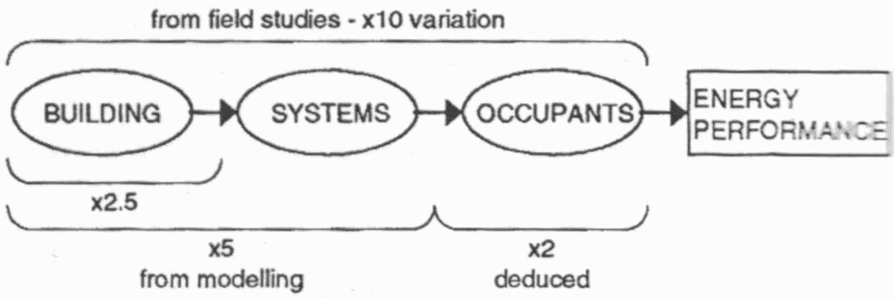


Figure 8: building system and occupant factors affecting energy consumption in non-domestic buildings

What is the relative contribution of these factors to the tenfold range in performance? According to figure 8, building design parameters cause variations in energy use by about 2.5 times. The building systems allow these variations to be extended to five times. Therefore, the occupants are responsible for the remaining twofold variation in energy use (Baker & Steemers 2000). Consequently, the aim of seamless environmental integration should mainly be focused on:

¬ *improving existing and creating new ecological linkages*

¬ *reducing the heat-island effect of the building on the surrounding built environment*

¬ *integrating with the wider urban context*

¬ *improving internal comfort conditions*

¬ *optimizing mixed-mode options in the designed system*

¬ *integrating renewable energy technologies for generating the energy required*

1.4. Aims of study

1.4.1 An existing office building as case-study for analysis

In this context, the analysis of the energy consumption and the respective carbon emissions over a public large-scale existing office building in Greece can result in a comprehensive understanding of how energy efficiency-upgrades can be critical when combating climate change. Tightening standards for new and existing buildings and their heating and cooling systems in Greece can reduce significantly the related emissions. According to the European Commission (2007), there is a potential of cutting energy consumption in buildings by 28% by 2020; this number is equivalent to saving more than 10% of the EU's total energy consumption. Hence, what are these improvements at existing office buildings that can cut down their energy requirements?

Aiming to reply to the previous question it is important to analyze an existing building in terms of energy consumption. Therefore, for the aims of this dissertation an ***existing office building*** is going to be analyzed. The analysis will include both the existing condition of the building and a potential improved condition that would enhance its environmental performance.

In other words, the building analysis intends to examine the effectiveness of passive design tools, from the one hand, and active methods, from the other, that will enhance the energy performance of the building making it more energy efficient and reducing its carbon emissions. More specifically, this dissertation focuses on implementing measures that efficiently control solar gains that, depending on the period, become desired or unwanted and at the next stage examining the potential of using renewable energy technology for energy generation to cover the building demands.

1.4.2 Examples of sustainable buildings

The following buildings are major case-studies that were used as pilot for scrutinizing the potential improvements to the building under analysis:

a) Offices 88 [London, UK] - Richard Rogers

Figure 9: general view of Offices

Figure 10: internal view of Offices 88

Figure 11: external view of offices 88

At this building the sophisticated glazing system allows maximum daylight penetration to all floors and incorporates integral internal blinds to protect the building from unwanted solar gain and glare (Rogers 2008). The innovative environmental element of this building has been the adjusted photocells that control the angle of the blinds reducing glare, heat gains and, consequently, energy consumption but its performance is closely related to the occupants' behavior.

b) Beddington Zero Energy Development (BEDZED) [Surrey, UK] - Bill Dunster Architects

Figure 12: general view of the Beddington community

BedZED is a zero carbon community that demonstrates comfortable and affordable energy efficient buildings. It does not rely on high tech solutions but is based on proven techniques to minimize energy demands. However, there have been problems reported associated with the orientation of the different facilities because of which changes to the initial masterplan were inevitable. Additionally, the final result may not be considered as aesthetically effective.

c) Solar office [Doxford, UK] - Studio E

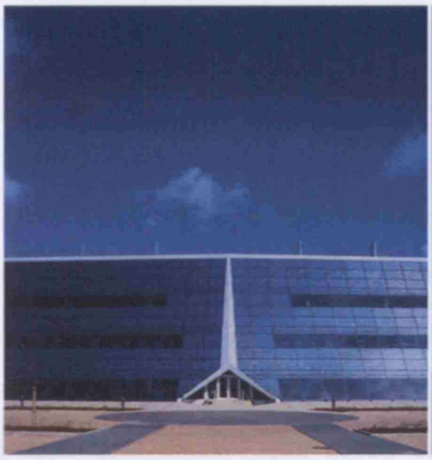


Figure 13: front view

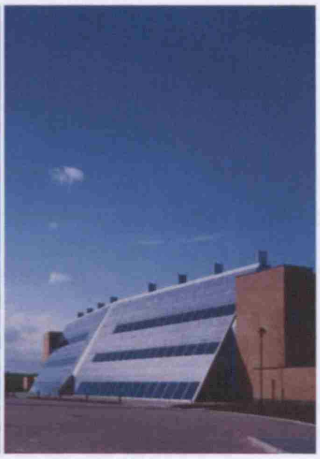


Figure 14: side view

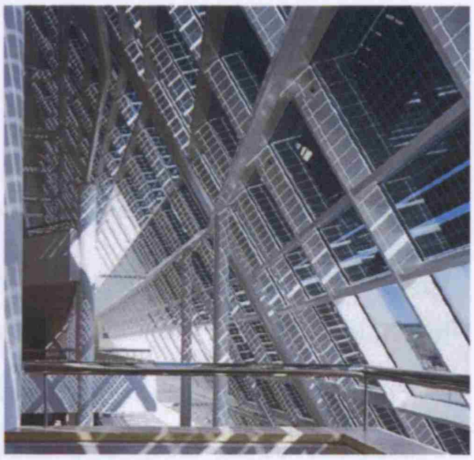


Figure 15: internal view of the PV façade

According to Studio E (2008), Doxford solar offices is the first speculatively constructed building to incorporate building integrated photovoltaics and the resulting facade was the largest assembled at the time. However, the high cost of the PV façade makes similar investments prohibitive. Besides, there have been problems related to the PV cells being less efficient than expected.

d) City Hall [London, UK] – Foster & Partners

Figure 16: general view of the City Hall

Figure 17: view of the roof PVs

The implementation of PVs in this building has demonstrated the feasibility of retrofitting landmark buildings with bespoke renewable energy technologies. However, there have been barriers to overcome that are associated with the integration of the normally rectangular PV panels on a curved surface in order to preserve its aesthetics (LCCA 2008), which increased the cost of the installation. At the same time alternative renewable energy sources, like wind energy, may have proven more effective.

1.4.3 Structure of analysis

Taking account of the aforementioned basic aims of study, the thesis is going to be structured according to the temporal stages of upgrade. In other words, the energy consumption analysis is made in consecutive levels graduating from the current condition of the building to the potential improved building envelope and then to making the building as independent from fossil-based energy as possible. The building is going to be analyzed in terms of energy consumption, according to the following steps:

- *analysis of the current building condition according to the energy data available*
- *thermal analysis of the building in order to extract qualitative results about the building energy performance which can be compared to the real data of the Building Energy Management System installed*
- *feasible improvements of the building envelope so as to allow passive architectural design contribute to the reduction of energy use*
- *application of photovoltaics to reduce dependence on fossil-based energy*

Chapter 2 includes the general description of the case-study building main characteristics (location, building description and climate analysis). Additionally, in this chapter a short descriptive analysis of how the building services operate is made in terms of a more comprehensive breakdown of the basic energy requirements.

Chapter 2: The case-study

2.1. General description of the building & climate analysis

2.1.1 Building main characteristics

The *General Secretariat for Information Systems (GSIS)* is a public administration agency of the Greek Ministry of Economy and Finance and Informatics center of the public sector and has around 1,400 employees. The building is located in Kallithea, an area approximately six kilometers southeast of the centre of Athens. The main urban characteristic of the building is that it is located next to a tube station allowing convenient access by public transport.

Figure 18: the GSIS building in the urban context

Figure 19: general view of the building

The GSIS office building was previously used to accommodate the "Petzetakis" factory and was built during the 1960s. In 1995 it was purchased by the ***Hellenic Republic Real Estate Corporation (HRREC)*** and was refurbished to accommodate the aforementioned facility. The new GSIS building is the result of a retrofitting of a pre-existing industrial building dating to the 60s (Queiroz Gaudin & Gaudin 2008). During the first years of the building operation there had been increased comfort problems because of inadequate thermal insulation, intense solar penetration and unresponsive air-conditioning.

Figure 20: south east view of the building

Figure 21: east view of the building

Figure 22: north view of the building

Figure 23: west view of the building

Figure 24: shading on the south façade

Figure 25: details on the east facade

The original design is a rectangular shape measuring 115 m in length and 39 m in width, with a total floor area of 30,000 m^2, of which 20,000 m^2 are allocated to office use. Its long axis runs along a south/southeast to north/northwest orientation. The GSIS building consists of the ground floor (with a mezzanine), four main floors and two basements (App. Figures 55-65). The reception hall, the auditorium, the printer halls and various offices are located on the ground floor. The upper four floors are mainly occupied by offices that are distributed along the building perimeter. In addition to the offices, on these floors there are also spaces allocated either for mechanical services or for other mechanical facilities (terminals, etc). It should be highlighted that there is an atrium running through the three upper levels. Apart from this one, a significantly larger atrium exists between the third and fourth floors (figure 30) allowing the physical contact between the two levels, from the one hand, and the effective use of daylight owing to the transparent ceiling, from the other.

Figure 26: interior view

Figure 27: interior view

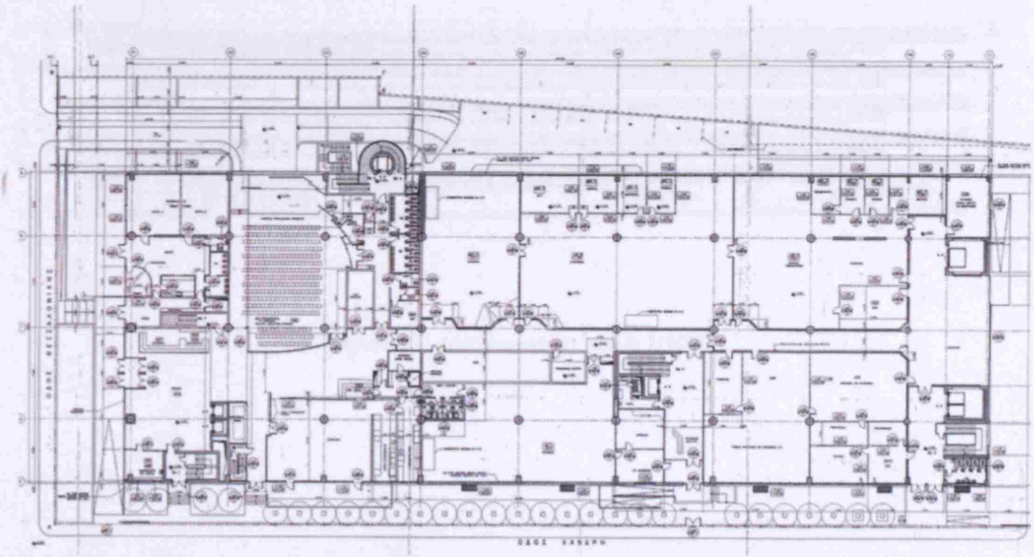


Figure 28: ground floor, scale 1:1000

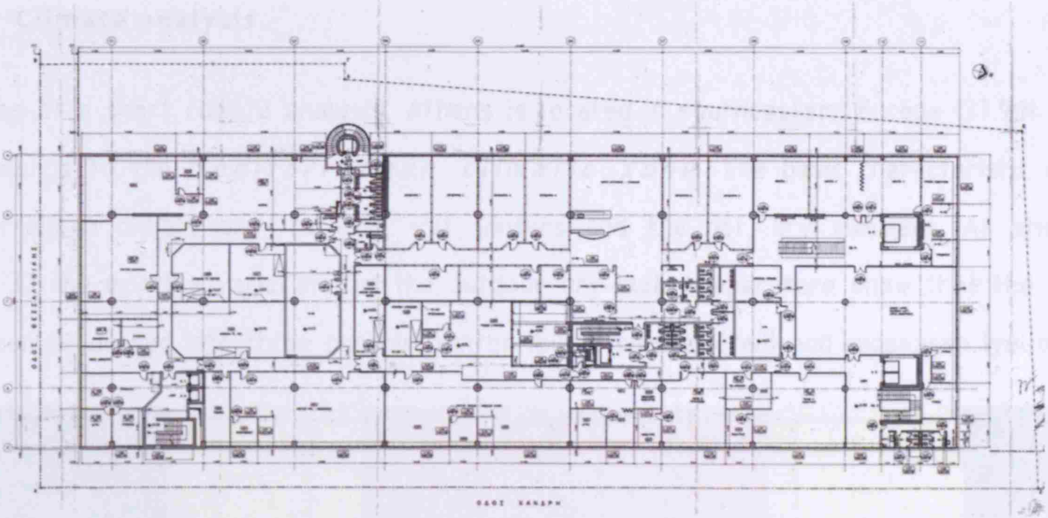


Figure 29: 1st floor, scale 1:1000

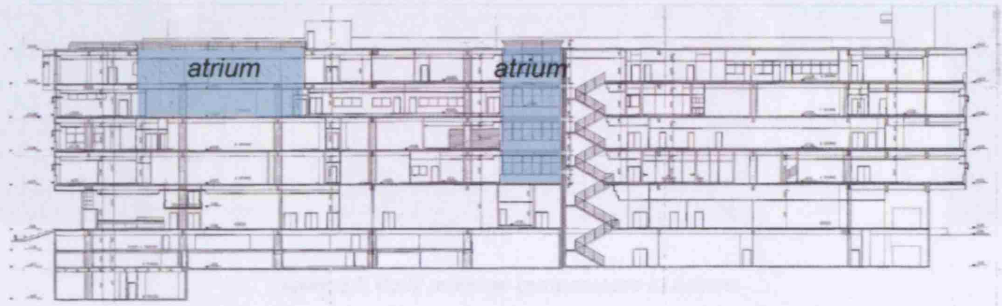


Figure 30: north-south section, scale 1:1000

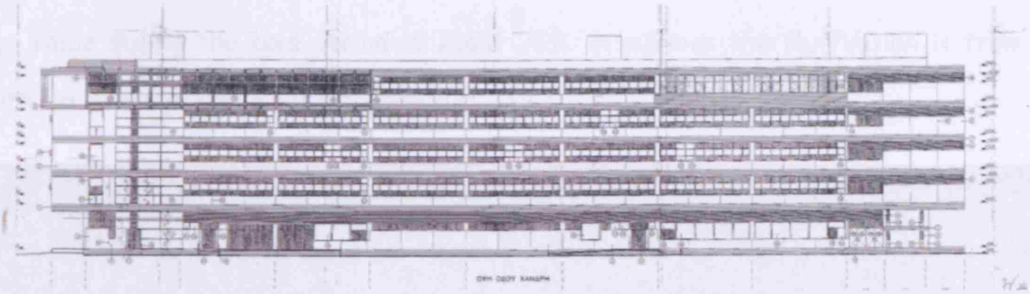


Figure 31: east elevation, scale 1:1000

2.1.2 Climate analysis

In terms of a short climate analysis, Athens is located in southeastern Europe (37.9°N 23.7°E) and belongs to the ***Mediterranean climatic zone***. The basic characteristic of the Mediterranean climate are the mild, wet winters and the hot, dry summers. As shown in figure 32 the monthly variations of the outdoor dry-bulb temperature show that the annual cycle can be divided into three periods; winter (blue), summer (red) and midseason (yellow).

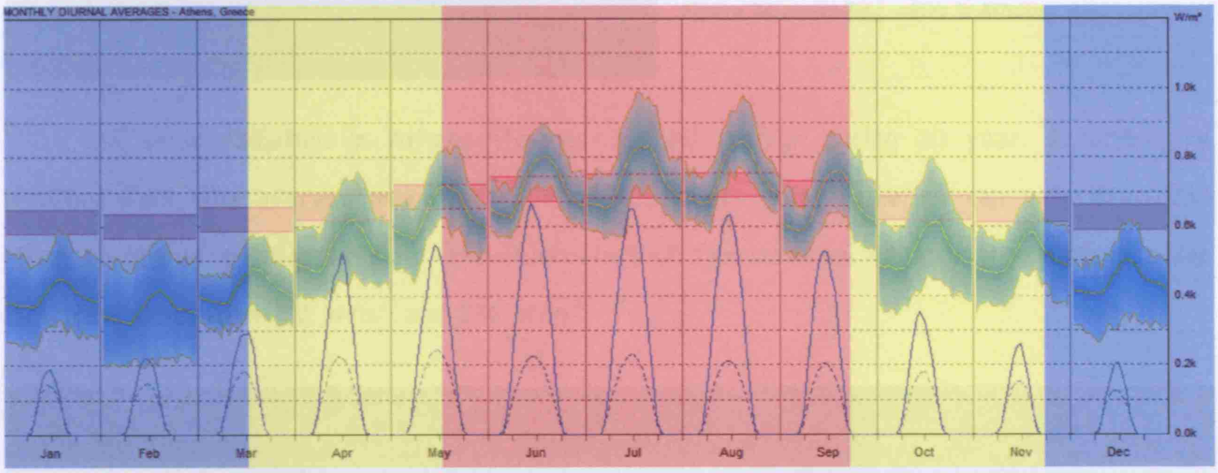


Figure 32: daily average temperature in Athens

In general, outdoor temperature varies from 0 °C (in the winter) to 40 °C (in hot summer days) with the average values at 8 °C and 26 °C respectively. As far as the relative humidity is concerned, during the wet winters, this fluctuates between 50% and 90%. The average value during the cold period is about 75%. In summer the fluctuation is from 20% to 60% with an average value 40% (figure 33).

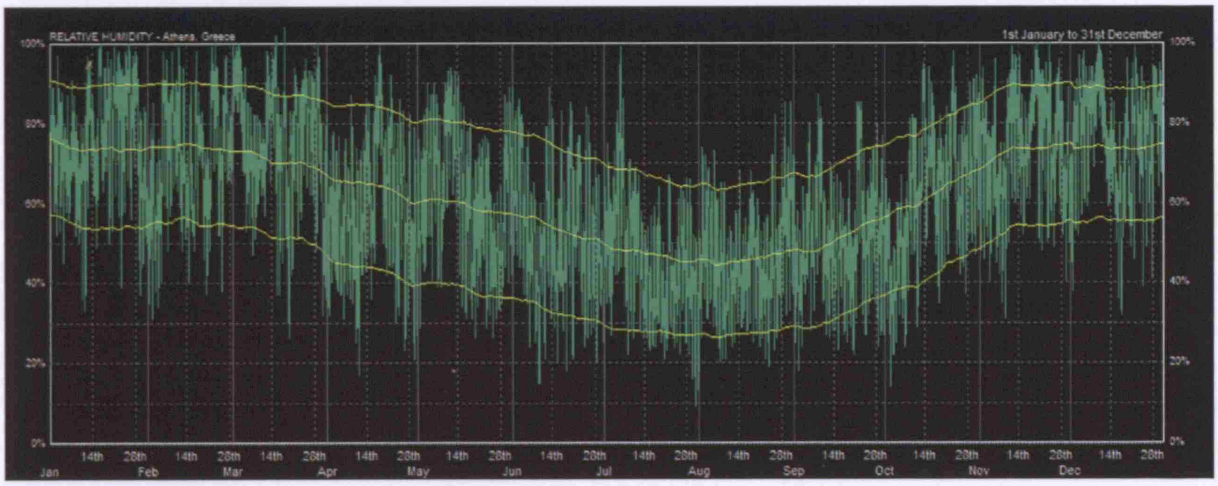
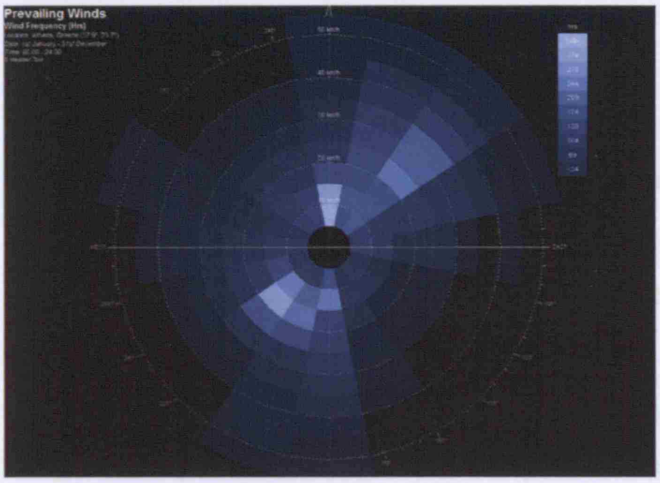


Figure 33: relative humidity in Athens



According to figure 34, the wind frequency direction of the prevailing winds during winter is mainly north and north/east, whereas in summer is south/southwest.

Figure 34: prevailing winds in Athens

The solar radiation in Athens (figures 35, 36) is high during all year. According to Weather Tool, the average maximum value of the direct solar radiation can vary from 250 W/m^2 to 650 W/m^2. Respectively, the fluctuation of the maximum value of the diffuse solar radiation is between 180 W/m^2 and 230 W/m^2.

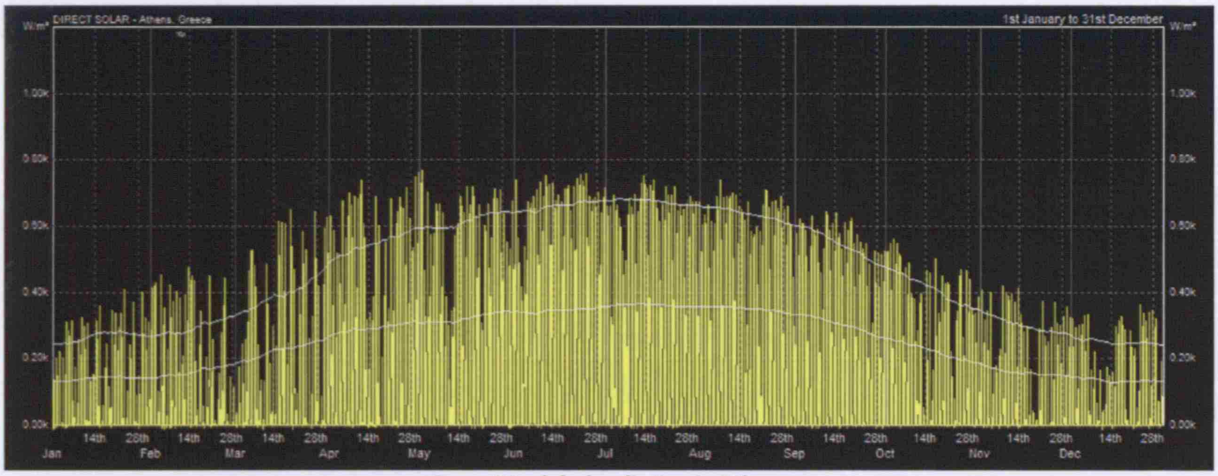


Figure 35: global radiation in Athens

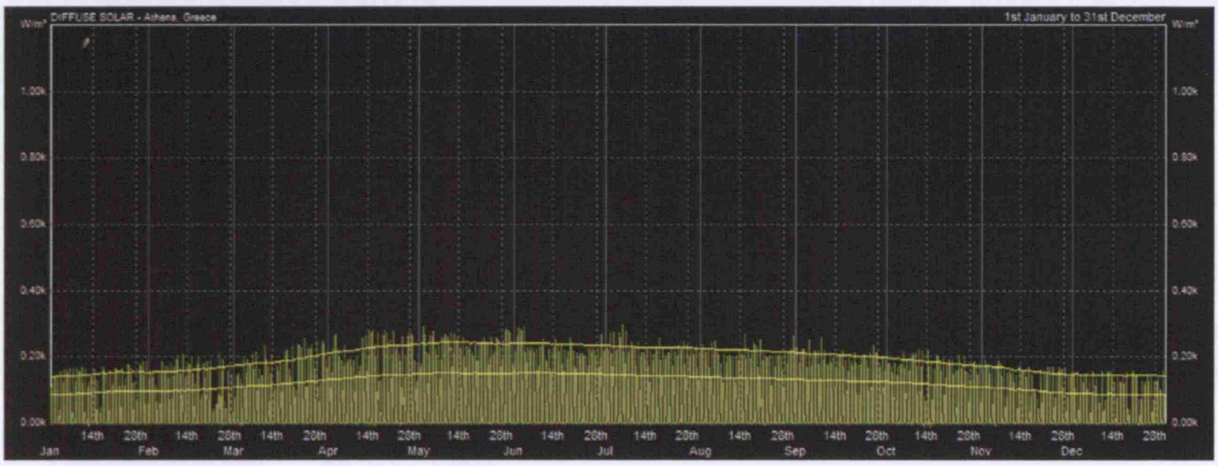


Figure 36: diffuse radiation in Athens

2.2. Current building energy performance

The GSIS building was included in the European Union research project *"REVIVAL" (Retrofitting for Environmental Viability Improvement of Valued Architectural Landmarks)*. Within this framework, the building went under major refurbishment aiming to improve indoor environmental conditions and reduce energy consumption and CO_2 emissions. A *Building Energy Management System (BEMS)* was installed to carry out measurements related to energy consumption (heating, cooling and lighting) and other comfort parameters (internal temperatures, relative humidity, CO_2 concentration etc.).

In general, the building refurbishment has included improved fabric performance, prevention of overheating and efficient cooling technologies and controls. The building has been upgraded to reduce the very high energy consumption and solar gains implementing architecturally designed external shading (Queiroz Gaudin & Gaudin 2008). These improvements include:

- *Shadings, designed by Alexandros Tombazis, attached to the south façade to more efficiently control solar gains*
- *change of the previous-existed glass windows with the brand new low-e glazing glass windows on the north façade to improve indoor conditions*
- *artificial lighting with photo control*
- *controlled and night ventilation up to 8 ACH*
- *ceiling fans to allow extension of the comfort zone up to an indoor air temperature of 28.5 °C*
- *heat recovery*
- *economizer on the cooling system*
- *new radio control system on the air conditioning*
- *installation of a photovoltaic area*

According to Farrou (2007), the aforementioned improvements have aimed at:

¬ ***Reduction of energy consumption:***

Upgrade of the heating and cooling systems in order to achieve reduced energy consumption (installation of circulating pumps of the inverter type controlled by BEMS, energy meters, vans in the fan coil units, central thermostats) and replacement of the common luminaires by high efficiency lamps.

¬ ***Improvement of comfort***

Installation of ceiling fans and occupancy sensors in the office areas to extend thermal comfort levels.

¬ ***Reduction of energy consumption <u>and</u> improvement of comfort:***

Demand control ventilation and installation of CO_2, humidity and temperature sensors to record indoor conditions. All sensors operate through the BEMS.

¬ ***Control and operation of the building services and record of energy consumption.***

Upgrade of the existing BEMS.

After the completion in 2007 of the improvements there has been a reduction in energy use by 31.3% compared to 2000. This is equivalent to 32.4% reduction in CO_2 emissions or 412 tons CO_2, whereas the generation of electricity from photovoltaics saves 2 tons of CO_2 annually.

2.3. Heating, Cooling, Ventilation

The improvements on the heating/cooling system have included the installation of circulating pumps of the inverter type controlled by the BEMS in relation to the internal and external temperature and the temperature difference between inlet and outlet of the heat water through the energy measures that have been installed in each boiler. A controller has been installed in every office giving the user an adjustment capability of +/-5 °C over the operation of the fan coil unit valve (Revival 2008).

The cooling system consists of a motorized valve that is controlled by a thermostat/transmitter combined with a valve controller. The thermostat transmits the temperature value to central controller in the ownership. The central controller is programmed for the temperature limits and the hours or operation of the ownership and it transmits a signal to the valve controller in order to activate it or not. The above mentioned controller will be set on a minimum cooling temperature of 26 °C. For the cooling consumption measurement an energy metering device has been installed in the area of each user. In this way each user will be have the possibility to control its own consumption. The reading of the energy meter will be transmitted to the above mentioned central controller (Revival 2008).

Demand controlled ventilation techniques are used to optimize and control indoor air quality. In addition to this, advanced hybrid ventilation techniques have been implemented in combination with optimal control of natural and mechanical ventilation systems (Revival 2008).

The appropriate services for full air-conditioning of the interior spaces have also been installed. The ventilation needs are covered by the air-conditioning system and the auxiliary mechanical ventilation system. In general, the building services need to ensure the following temperature conditions:

a. Summer

¬ Dry bulb temperature: 27 °C

¬ Relative Humidity: 50%

b. Winter

¬ Dry bulb temperature: 20 °C

¬ Relative Humidity: 45%

at the following outdoor conditions of air:

c. Summer

¬ Dry bulb temperature: 36.5 °C

¬ Wet bulb temperature: 25 °C

¬ Diurnal temperature variations: 16 °C

¬ Relative Humidity: 40%

d. Winter

¬ Dry bulb temperature: 0 °C

In the next chapter the data collected from the BEMS are going to be analyzed in order to estimate the annual energy consumption of the building and afterwards define its carbon footprint.

In chapter 3 the collected data from the Building Energy Management System of the Building installed at the case-study building are presented. These include total energy consumption and more specifically energy for heating, cooling and lighting. After analyzing these data, energy consumption is translated then in carbon footprint i.e. carbon emissions, so that there is a more comprehensive understanding of how energy use is related to GHG emissions.

Chapter 3: Current energy consumption

3.1. Analysis of the BEMS data

The building refurbishment has aimed at the optimization of the mechanisms that influence the energy consumption. Therefore, the essential changes at the building services were made. Additionally, the BEMS system installed to control the lighting, air quality, heating and cooling systems has resulted in the optimization and rationalization of energy needs. In order to avoid wiring and to easy adapt the system to future needs, the system is wireless. So, the main advantage of the system is the possibility to change the operation mode of the system or to expand it without replacing materials or changing the control software (NKUA 2008).

Internal temperatures (°C)				
Data entry room	***min***	***max***	***average***	***median***
Jun-07				
B21	*14.93*	*28.57*	*24.11*	*25.29*
B22	*24.10*	*30.18*	*27.05*	*27.10*
B23	*22.12*	*29.05*	*26.56*	*26.57*
B26	*26.39*	*30.37*	*27.89*	*27.80*
B28	*25.64*	*30.16*	*27.73*	*27.72*
Jul-07				
B21	*16.24*	*30.53*	*24.54*	*26.40*
B22	*22.83*	*29.94*	*27.10*	*27.15*
B23	*23.04*	*29.02*	*26.81*	*26.84*
B26	*25.22*	*31.46*	*27.91*	*27.96*
B28	*26.24*	*31.12*	*28.13*	*28.01*
Aug-07				
B21	*15.65*	*30.46*	*25.11*	*26.77*
B22	*22.38*	*30.38*	*27.12*	*27.07*
B23	*22.89*	*30.11*	*26.77*	*26.75*
B26	*24.40*	*31.20*	*27.37*	*27.32*
B28	*26.07*	*31.58*	*28.12*	*28.10*

The recorded internal temperatures show that during summer months in 2007 the average temperatures in the data entry rooms varied from 24.1 to 28.1 °C. and the median temperatures from 25.3 to 28.1 °C. During the same period maximum temperatures have exceeded 30 °C almost in all data entry rooms (NKUA 2008). The analysis of the monitored results shows that higher temperatures are recorded in the Data entry rooms B2.6 and B2.8 that have a northern-northeastern orientation (figure 37).

Table 1: internal temperatures in summer 2007 (NKUA 2008)

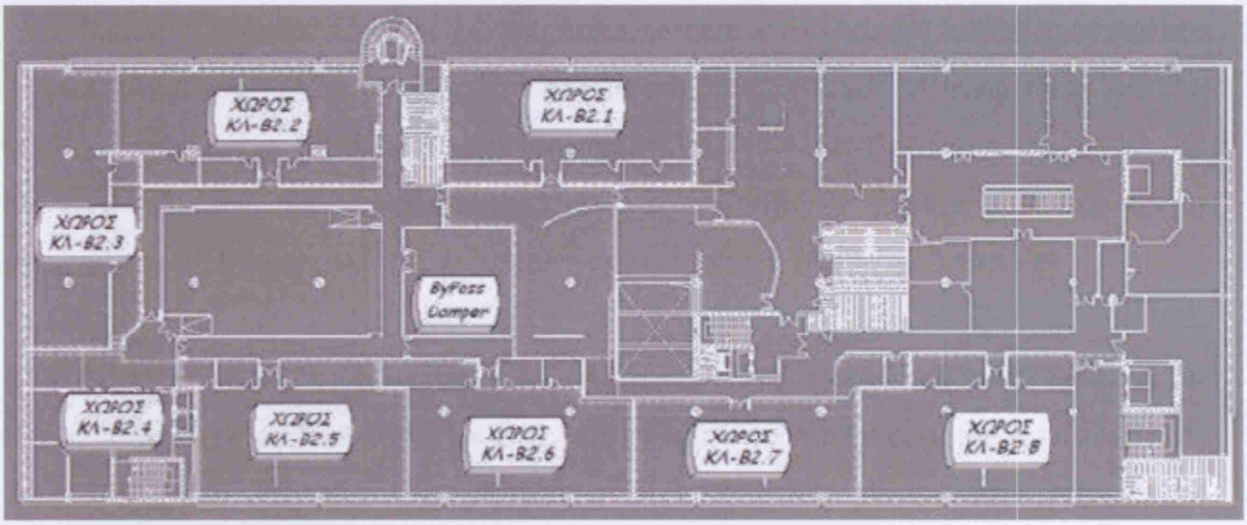


Figure 37: BEMS screen showing the areas of data entry rooms of the second floor

Figure 38 shows the ambient temperatures at Athens during summer 2007 which has been extremely hot. The maximum temperatures fluctuate between 41 and 43 °C. Despite the extreme external conditions the thermal comfort levels in the data entry rooms remained constant and below the external temperatures by at least 10 °C.

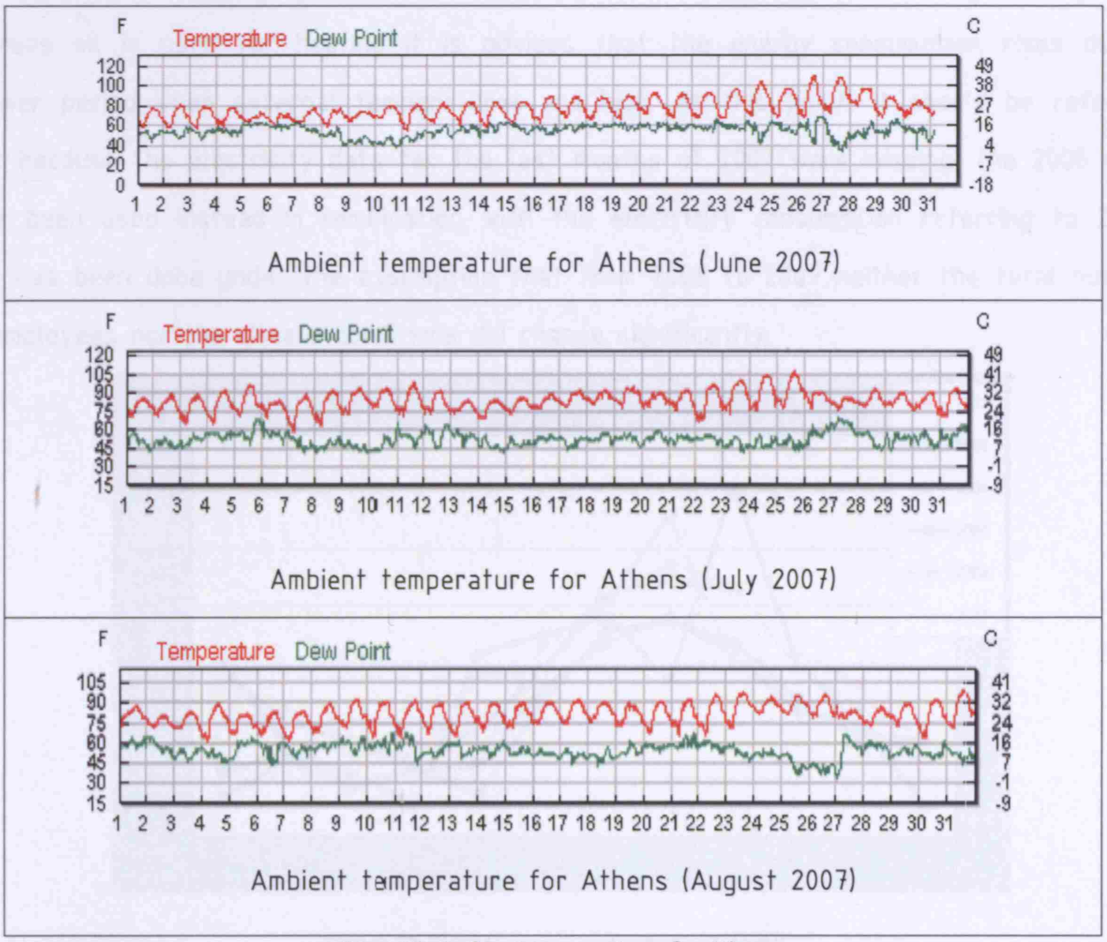


Figure 38: Ambient temperatures for Athens

The data collected from HRREC and Axima services have included energy consumptions in electricity (MWh) and oil (l) during the heating period as a result of using fossil fuel for heating. Consequently, the total energy consumption of the building derives when summing up the electricity and the oil consumption. However, in order to achieve a unified energy consumption result it is essential to convert oil consumption to energy (l to kWh).

Petrol is a highly concentrated energy source. So, as Carbon Trust (2008) explains, one litre of fuel oil yields 11.69 kWh of energy. According to the HRREC data the total electricity used during 2007 has been 4,019,000 kWh or ***4,019 MWh***. At the same year the oil consumption approached ***75,500 lt***, which is equivalent to 75,500 x 11.69 = 882.595 kWh or ***883 MWh***. So, the ***total annual energy consumption*** for the year 2007 has been 4,019 + 883 = ***4,902 MWh***.

Figures 39, 40 present the electric energy consumption per month and the maximum peak load. Since electricity is used for cooling besides lighting and electrical equipment, whereas oil is used for heating it is obvious that the energy consumption rises during summer period when external temperatures are high. At this point, it should be referred that because the electricity data for the last months of 2007 were missing, the 2006 data have been used instead in combination with the electricity consumption referring to 2007. This has been done under the assumption that from 2006 to 2007 neither the total number of employees nor the climate conditions did change significantly.

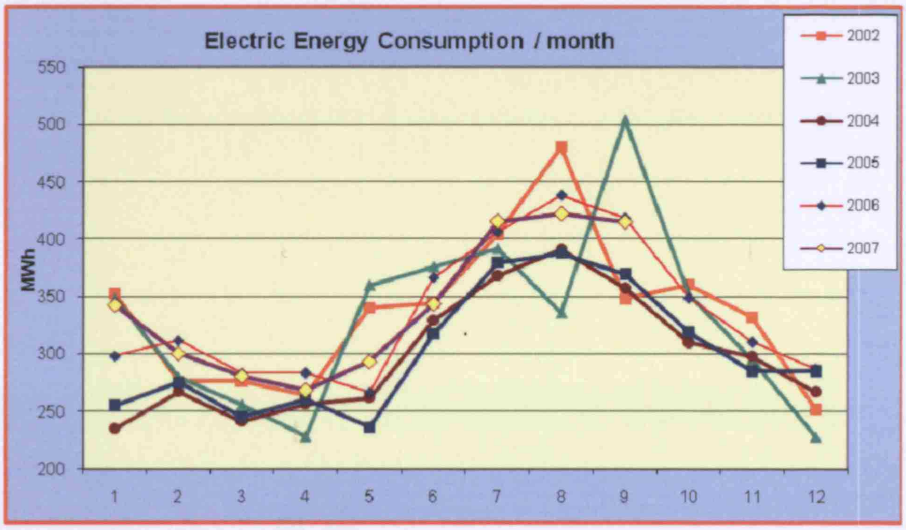


Figure 39: Electric energy consumption/month

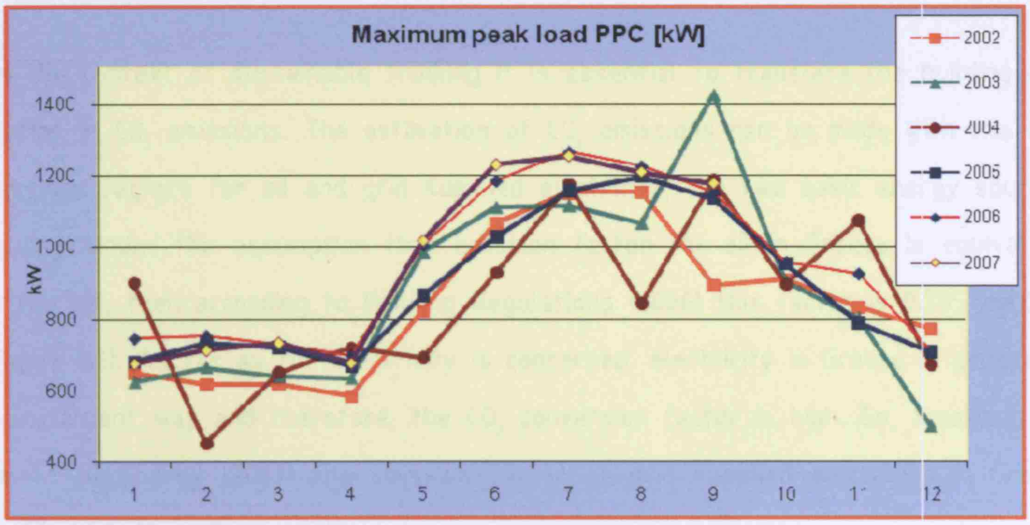


Figure 40: Maximum peak load Public Power Corporation

3.2. Carbon footprint

In the context of sustainable thinking it is essential to translate the building energy consumption in CO_2 emissions. The estimation of CO_2 emissions can be made with the use of the emissions factors for oil and grid supplied electricity, the two basic energy sources of the building. Under the assumption that emission factor for oil in Greece is equivalent to that in the UK, then according to Building Regulations (2006) this factor is 0.265 $kgCO_2/kWh$ (App. Figure 66). As far as the electricity is concerned, electricity in Greece is generated in a very inefficient way and therefore, the CO_2 conversion factor is high. So, according to US Department of Energy (2007) the emission factor of grid supplied electricity in Greece is 0.887 $kgCO_2/kWh$ (App. Figure 67).

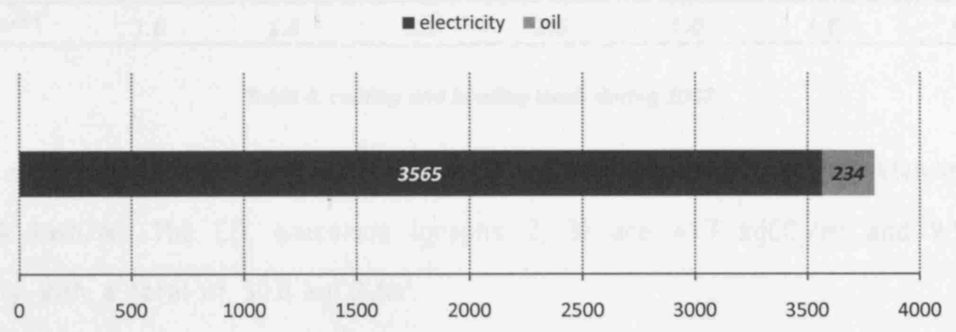
Greece	*CO_2 emission factors $kgCO_2/kWh$*
Oil	***0.265***
Grid supplied electricity	***0.887***

Table 2: CO_2 emission factors in Greece

Consequently, the CO_2 emissions of the GSIS building are calculated according to table 3 and approach 3,799 tons of CO_2 annually.

fuel	*Energy consumption (kWh)*	*Emission factor ($kgCO_2/kWh$)*	*CO_2 emission ($kgCO_2$)*	*CO_2 emission ($tonsCO_2$)*
Oil	***883,000***	***0.265***	***233,995***	***234***
Grid supplied electricity	***4,019,000***	***0.887***	***3,564,853***	***3,565***
Total	***--***	***--***	***3,798,848***	***3,799***

Table 3: annual energy consumption and CO_2 emissions in relation to the emission factors



Graph 1: annual CO_2 emissions from cooling and heating ($tonsCO_2$)

3.3. Energy for heating, cooling & lighting

Office buildings must satisfy high demands with regard to the flexibility of their plan layouts. One primary requirement is to retrofit building services easily (Richarz et al 2007). Therefore, the operation and the control of the heating and cooling systems has been upgraded. Specifically, the ***control of heating*** is performed at the level of distribution. Circulating pumps of the inverter type are installed and connected to the BEMS.

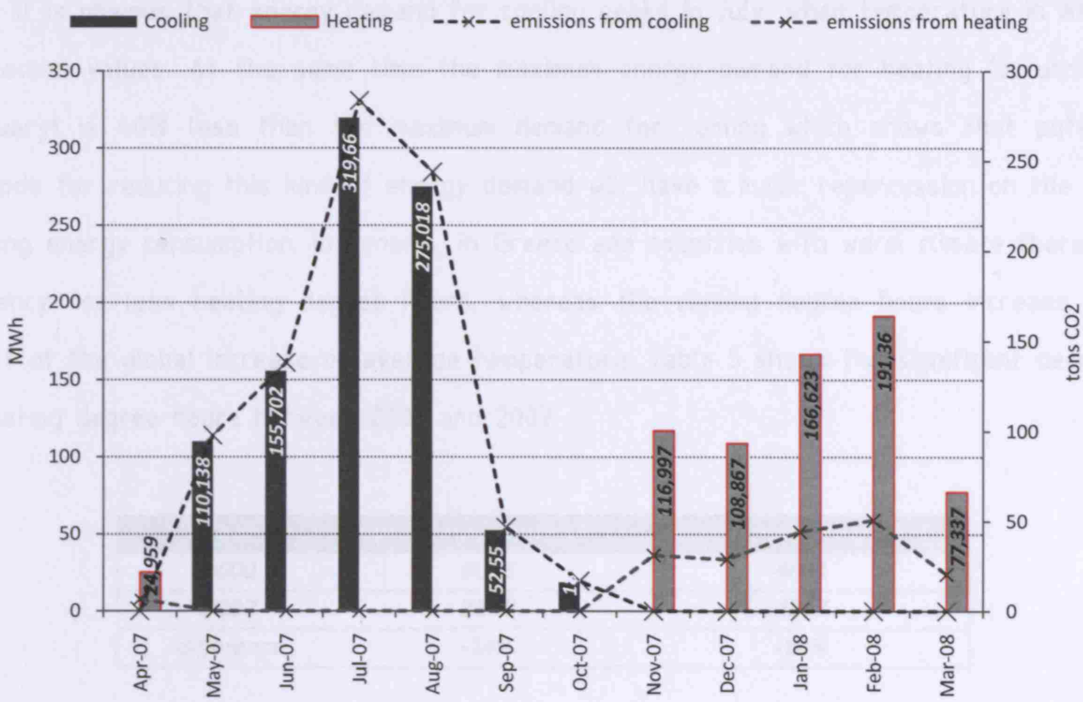
At the same time, the ***control of cooling*** is performed at the level of the user and at the level of distribution. Valves are installed in the fan coil units to control the water flow for cooling, whereas fans are connected to thermostats. Central thermostats (sensors) of temperature are installed for each fan coil unit or group of units. Additionally, energy meters are installed to monitor the overall energy consumption (NKUA 2008).

According to table 4, the total annual energy for 2007 for heating is ***686 MWh*** and for cooling ***932 MWh***. Therefore, the total energy for heating and cooling is ***1,618 MWh***, which is equivalent to 33% of the total energy consumption (4,902 MWh). The energy consumption for heating and cooling were given by the monitoring team of the building from the ***National and Kapodistrian University of Athens (NKUA)***.

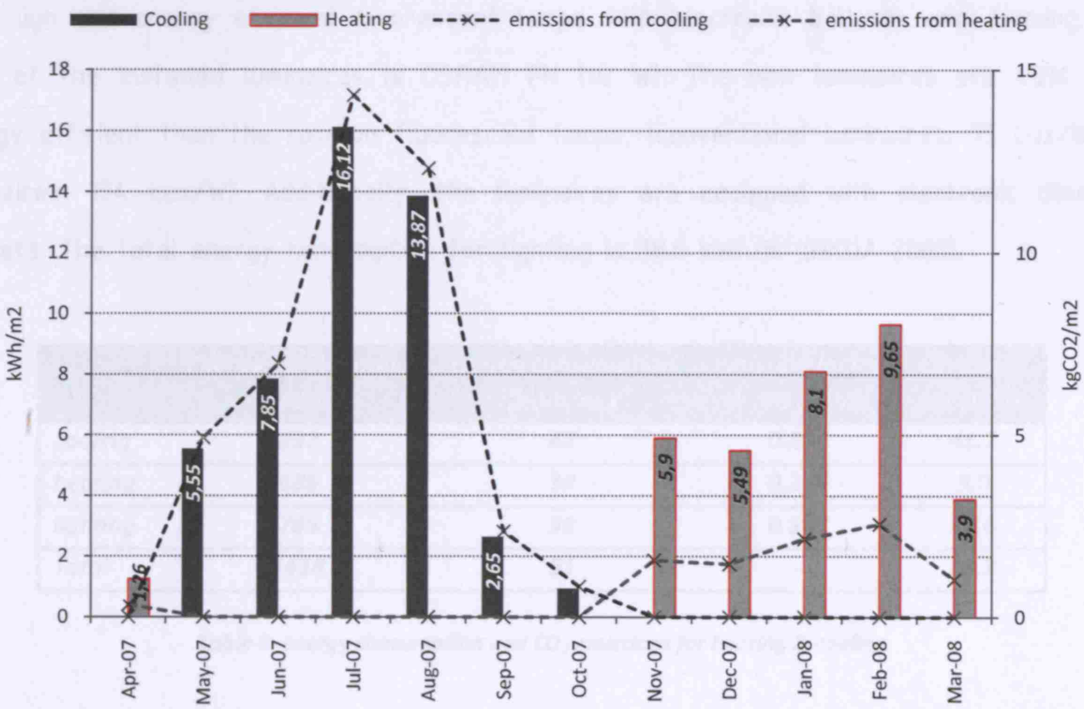
Cooling load	*May-07*	*Jun-07*	*Jul-07*	*Aug-07*	*Sep-07*	*Oct-07*	*Total*
Total (kWh)	***110,138***	***155,702***	***319,660***	***275,018***	***52,550***	***18,839***	***931,905***
kWh/m²	***5.6***	***7.9***	***16.1***	***13.9***	***2.7***	***1.0***	***47.0***
$kgCO_2/m^2$	***4.9***	***7.0***	***14.3***	***12.3***	***2.4***	***0.8***	***41.7***
Heating load	*Apr-07*	*Nov-07*	*Dec-07*	*Jan-08*	*Feb-08*	*Mar-08*	*Total*
Total (kWh)	***24,959***	***116,997***	***108,867***	***166,623***	***191,36***	***77,337***	***686,143***
kWh/m²	***1.3***	***5.9***	***5.5***	***8.1***	***9.7***	***3.9***	***34.3***
$kgCO_2/m^2$	***1.6***	***1.5***	***2.1***	***2.6***	***1.0***	***1.6***	***9.1***

Table 4: cooling and heating loads during 2007

In other words, the annual energy consumption for cooling is 47 kWh/m^2 and for heating 34 kWh/m^2. The CO_2 emissions (graphs 2, 3) are 41.7 $kgCO_2/m^2$ and 9.1 $kgCO_2/m^2$ respectively with a total of 50.8 $kgCO_2/m^2$.



Graph 2: monthly energy consumption and CO_2 emissions for heating and cooling (April '07 – March '08)



Graph 3: monthly energy consumption and CO_2 emissions for heating and cooling per unit area (April '07 – March '08)

It is obvious that energy demand for cooling peaks in July, when temperature in Athens hit record values. At the same time the maximum energy demand for heating (occurring in February) is 40% less than the maximum demand for cooling which shows that potential methods for reducing this kind of energy demand will have a major repercussion on the total building energy consumption. In general, in Greece and countries with warm climate there is a tendency for less heating degree hours, whereas the cooling degree hours increase as a result of the global increase of average temperature. Table 5 shows the significant decrease in heating degree hours between 2000 and 2007.

Year	*Base temperature 18 °C*	*Base temperature 20 °C*
2000	***4096***	***4691***
2007	***3540***	***4217***
difference	***-14%***	***-10%***

Table 5: heating degree hours in 2000 and 2007 (NKUA 2008)

After the recent renovation all luminaires of the data entry rooms have been replaced with high and energy efficient fluorescent lamps with electronic ballasts and dimming. The type of the installed luminaires is OSRAM FH (14 W). The new luminaires are 40% more energy efficient than the common fluorescent lamps, (conventional luminaires: 75 Lux/W, T5 luminaires: 104 Lux/W). Additionally, the luminaires are equipped with electronic dimmable ballasts. The total energy consumption for lighting is 38.6 kWh/m^2 (NKUA 2008).

	Energy consumption (MWh)	*Energy consumption (kWh/m^2)*	*Emission factor (kgCO$_2$/kWh)*	*Emissions kgCO$_2$/m^2*
cooling	***932***	***47***	***0.887***	***41.7***
heating	***686***	***34***	***0.265***	***9.0***
lighting	***765***	***39***	***0.887***	***34.6***
Total	***1618***	***81***	***--***	***85.3***

Table 6: energy consumption and CO$_2$ emissions for heating & cooling

Chapter 4 describes the main principles under which the case-study building has been modeled with the use of thermal analysis software. After completing its simulation, the energy consumption results for heating and cooling are analyzed and related to the existing energy data.

Chapter 4: Iterative thermal simulation

4.1. General framework

Taking account of all the aforementioned data about the existing upgraded condition of the GSIS building, it can be modeled with the use of thermal analysis software in order to analyze its energy performance. This analysis can show how energy demand is distributed over different areas of the buildings, indicating its most demanding parts.

After achieving practical results, a more comprehensive breakdown can be made in order to examine the potential for additional upgrades of the building. These upgrades will have manifold beneficial effects for the building and the built environment in general; on the one hand, considerable amounts of energy can be conserved and on the other, reductions in CO_2 emissions can be achieved. In addition to these, it is crucial to refer that the implementation of renewable energy technologies can lower building's reliance on energy generated from fossil fuels enabling its zero-carbon identity.

In this context, the building environmental analysis was made with the use of the thermal analysis software TAS. In order to achieve the optimum results the building was analyzed according to its current condition. Its thermal analysis was mainly focused on the various office areas that are occupied by the employees and are responsible for the largest portion of energy consumption. At the offices almost all the HVAC systems cooperate, whereas the areas with the machinery cannot be differentiated in terms of energy needs as their energy requirements are specific. Prior to the building simulation the appropriate data were collected mainly by three main sources:

a. The HPREC, proprietor of the building, which provided all the plans of the building and a significant amount of energy data and external weather conditions during 2002-2007.

b. The Axima Services Greece, responsible for the building maintenance, that offered a detailed description of the building services and how these are related to energy consumption

c. The Santamouris group at NKUA that provided all the energy data for the recent year.

It is obvious that an in-depth monitoring of the building would produce specific results about internal conditions (temperature and relative humidity levels). However, this method was not used because of difficulties related to the large scale of the building and the physical distance from it that would not allow its proper monitoring. Apart from this, the collected data from the BEMS system proved sufficient in order to carry out the energy analysis.

The aim was to design a relatively simple model in TAS that could lead to practical results. At an early stage attempts to create a more complicated model resulted in simulation problems due to the drastically increased file size. As a result a more simplified model was preferred in order to achieve practical relative results. However, the model has been kept as close to reality as possible. The steps of the simulation procedure are described at the following subchapters.

4.2. Simulation stages

The TAS simulation has included the following steps:

¬ The dimensions of the building spaces were obtained from the imported scanned plans and as a result they may not match accurately the real dimensions. However, they do not differ from the real dimensions considerably.

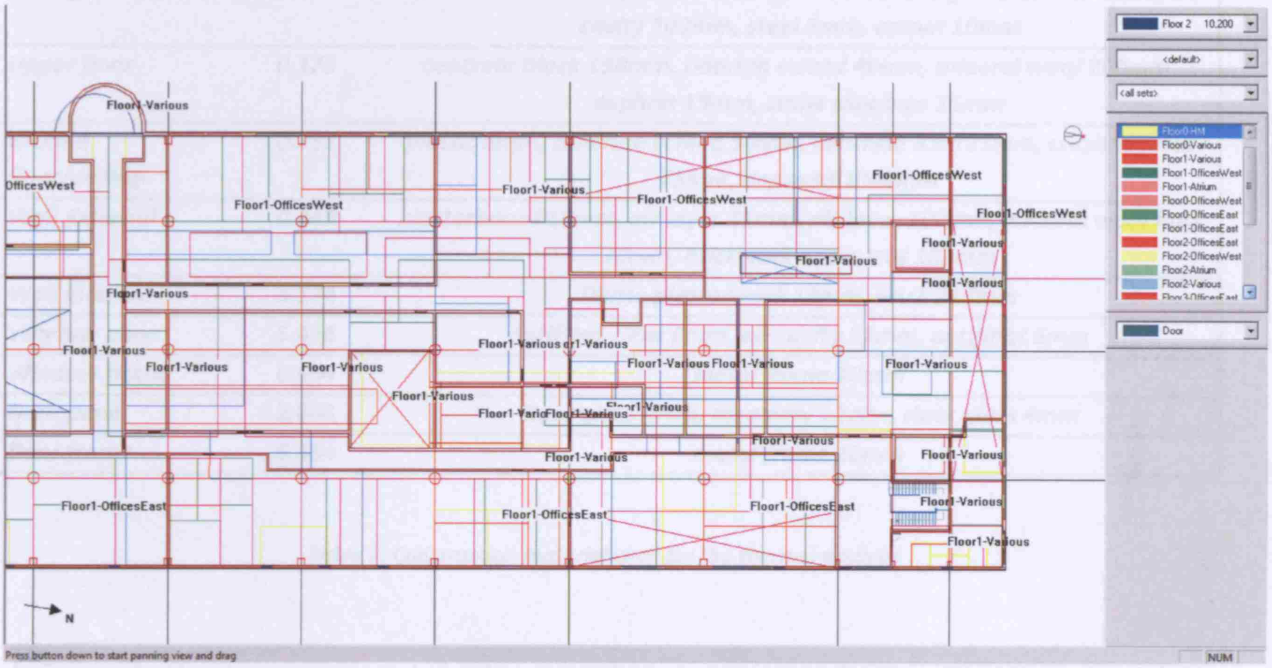


Figure 41: 2d representation of the building in TAS

¬ The floor plans were designed as being simpler than the real ones but kept to a detail level that would not influence the energy performance of the model. For instance, curved walls were designed as being linear and fragmented offices were unified to wider areas as this has little to marginal influence on the energy consumption of the building.

¬ One type of wall for the external walls and an additional one for the internal walls were used in terms of simplification.

¬ The prolonged openings along the building perimeter were designed under the assumption that the use of appropriate prolonged windows instead of smaller fragmented windows would not influence the results and would simplify the simulation procedure. As a result nominal windows of 1,2,3 and 4 m opening size replaced the real windows which approach the opening of 1 m.

¬ The constructions of the building elements was made according to table 7.

Construction	*U-Value (W/m^2C)*	*Construction material*
Ceiling	***0.338***	***concrete 3% 200mm, concrete screed 50mm, cork granulated 100mm, air cavity 100mm, steel 5mm, carpet 10mm***
Upper floor	***0.173***	***concrete block 150mm, flooring screed 40mm, mineral wool 200mm, asphalt 19mm, stone clippings 25mm***
Ground floor/ceiling	***0.297***	***plastic 5mm, concrete screed 50mm, concrete 3% 125mm, crushed brick 75mm, dry sand 1000mm***
Wall External	***0.449***	***plasterboard 13mm, air layer 25mm, air layer 100mm, mineral wool batt 70mm, brickwork outer leaf 102mm***
Wall Internal	***3.174***	***Dense plasterwork 13mm, brick 225mm***
Window pane	***5.458***	***optifloat clear 6mm, air cavity 12mm, optifloat 6mm***
Window frame	***6.554***	***metal frame 20mm***
Door pane	***2.804***	***Clear glass 4mm, air cavity 12mm, clear glass 4mm***
Door frame	***6.554***	***metal frame 20mm***

Table 7: Construction material used for the thermal analysis

¬ The calendar was assessed in three different seasons dividing the tear into four consecutive periods: winter-midseason-summer-midseason.

¬ The infiltration rate is set to 0.3 in accordance to Cibse Guide A (App. Figure --).

¬ The ventilation rate of the areas with no mechanical ventilation is assumed to be equal to zero. At areas with mechanical ventilation, the ventilation rate has been calculated under the assumption that the average density in the offices is 0.4 person/m^2. Accordingly, the number of Air Changes per Hour are set to 3.0, as explained on table 8 for the case of a 1 m^2 area.

Area	Height	Volume	Occupation density	Fresh air Vent. Rate (lt/sec/per)	Fresh air Vent. Rate (lt/h/per)	ACH (h^{-1})
1 m^2	**4.4 m**	**4.4 m^3**	**0.4 person/m^2**	**10 l/sec**	**14.400**	**3.3 ≈ 3.0**

Table 8: Air changes per hour

- Night ventilation was used for the passive cooling of the building. Therefore, night ventilation is used only during midseason and summer.

- The thermostats are set with the upper limit to 26 °C and the lower limit to 20 °C that are typical values for Greece.

- Therefore, eleven different internal conditions are defined in order to be allocated to the zones. The internal gains of the zones were set according to Cibse Guide A (2006) benchmark allowance for typical buildings (App. Figure 68). A more detailed calculation of the internal gains in each different zone would have been inaccurate due to lack of detailed data related to the occupancy density. Accordingly the internal zones are illustrated on the next table:

Internal Condition	Lighting gain	Occupancy sensible gain	Occupancy latent gain	Equipment sensible gain	Equipment latent gain
Basement	10.00	4.00	3.00	10.00	0.00
Basic air-conditioned office	12.00	10.00	5.00	15.00	0.00
Offices 1,4 - Summer	12.00	6.70	5.00	15.00	0.00
Offices 1,4 - Winter	12.00	6.70	5.00	15.00	0.00
Offices 1,4 - Midseason	12.00	6.70	5.00	15.00	0.00
Offices 2,3 - Summer	12.00	6.70	5.00	15.00	0.00
Offices 2,3 - Winter	12.00	6.70	5.00	15.00	0.00
Offices 2,3 - Midseason	12.00	6.70	5.00	15.00	0.00
Offices ground floor	12.00	5.00	4.00	12.00	0.00
Unconditioned atrium	5.00	4.00	2.00	0.00	0.00
Various	12.00	5.00	4.00	5.00	0.00

Table 9: Internal conditions

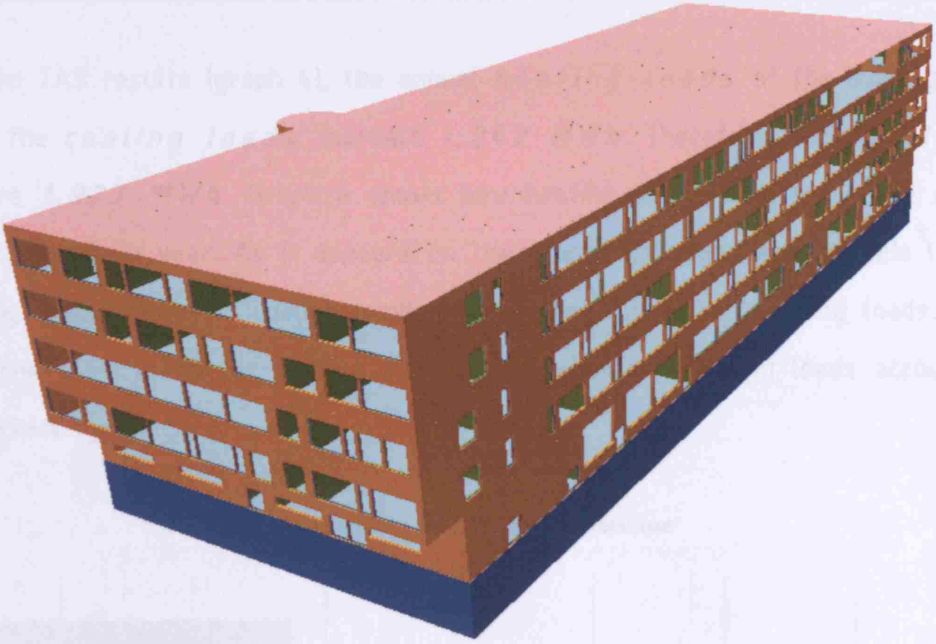


Figure 42: 3d representation in TAS of the building

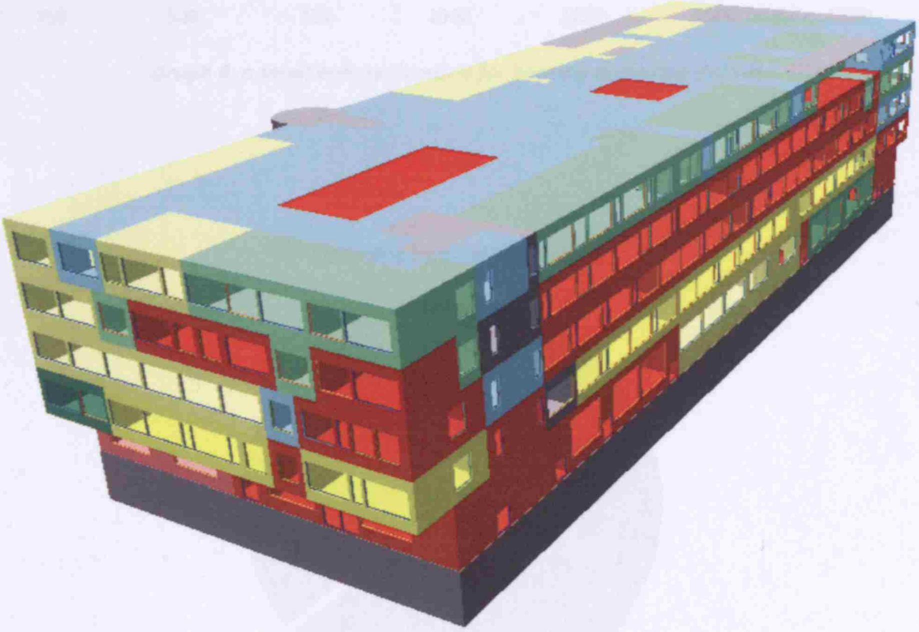
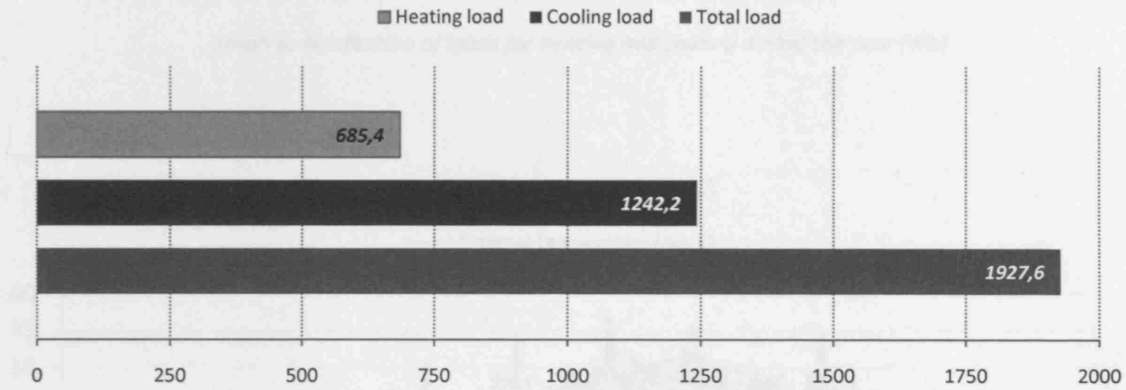


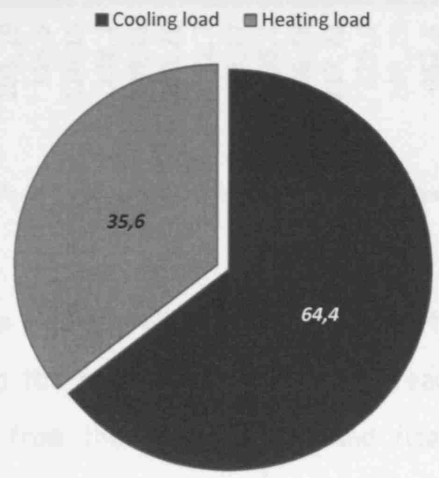
Figure 43: 3d representation in TAS of the building zones

4.3. Simulation energy results

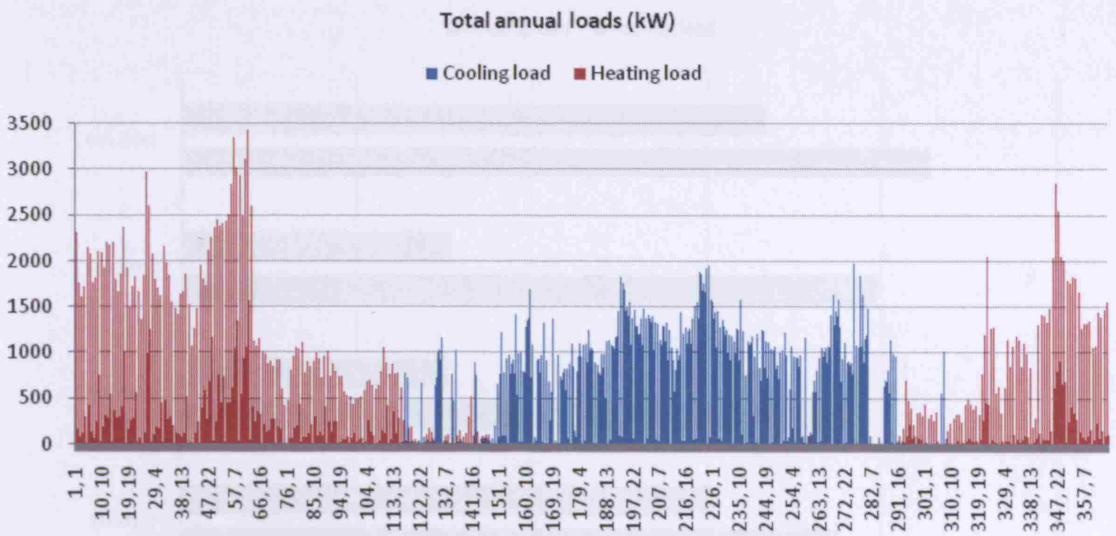
According to TAS results (graph 4), the annual ***heating loads*** of the building are ***685 MWh*** and the ***cooling loads*** approach ***1,242 MWh***. Therefore, the ***total annual loads*** are ***1,927 MWh***. Graph 6 shows how heating and cooling loads are distributed throughout the whole year. As it appears on the graph, although heating loads last longer than cooling loads, however, cooling loads are significantly higher. Cooling loads represent 64.4% of the total loads for heating and cooling, wehereas heating loads account fo the remaining 35.6% (grpah 5).



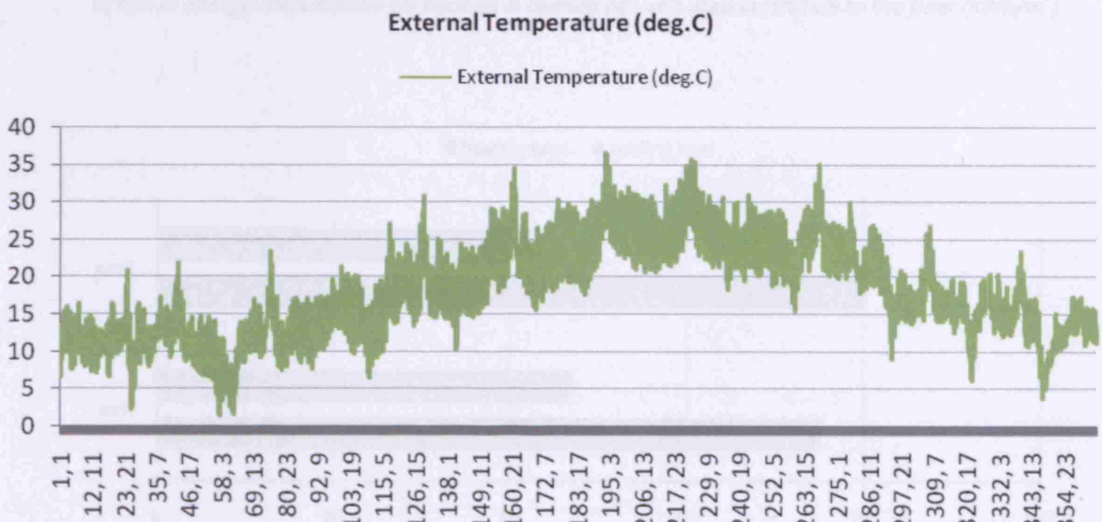
Graph 4: annual energy demand for heating & cooling (MWh)



Graph 5: Ratio of annual demands for heating & cooling (%)

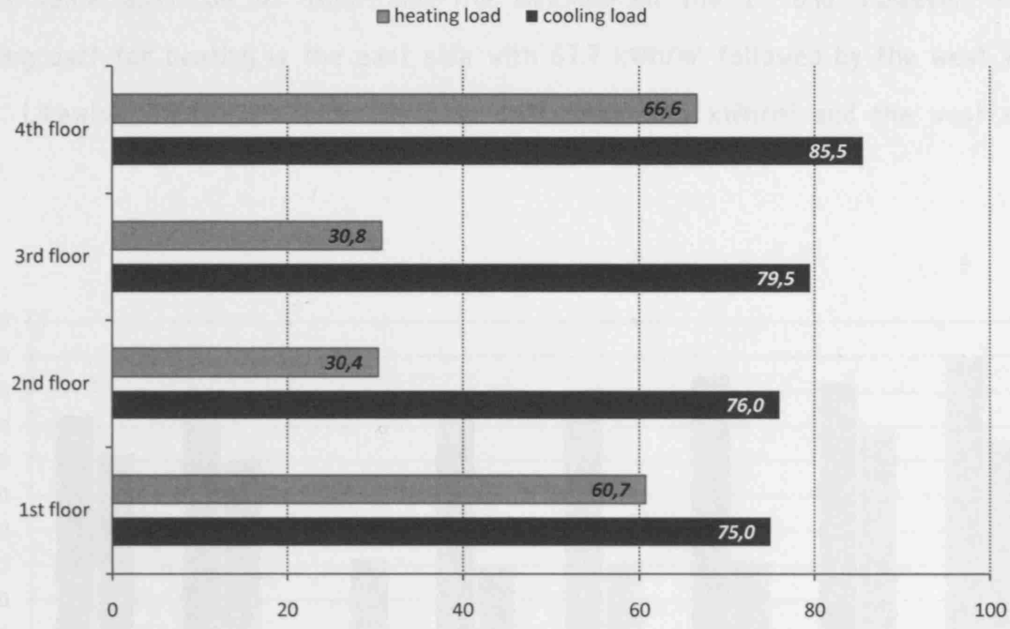


Graph 6: distribution of loads for heating and cooling during the year (Wh)

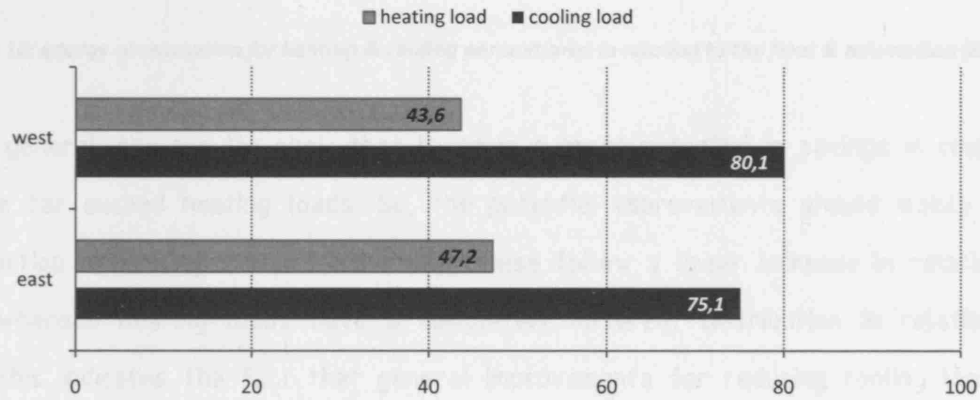


Graph 7: external temperature during the simulated year (°C)

Graph 8 shows that the higher cooling loads appear on the 4th floor and they decrease gradually to the 1st floor. On the contrary, heating loads reach their maximum value on the 4th floor dropping gradually from the 2nd to the 3rd and finally increasing again on the 1st floor. Furthermore, the graph 9 illustrates how loads are distributed in relation to the orientation. It is obvious that more cooling loads appear on the west side of the building, whereas heating loads remain approximately equal for the west and east side, however they to tend to increase on the east side.

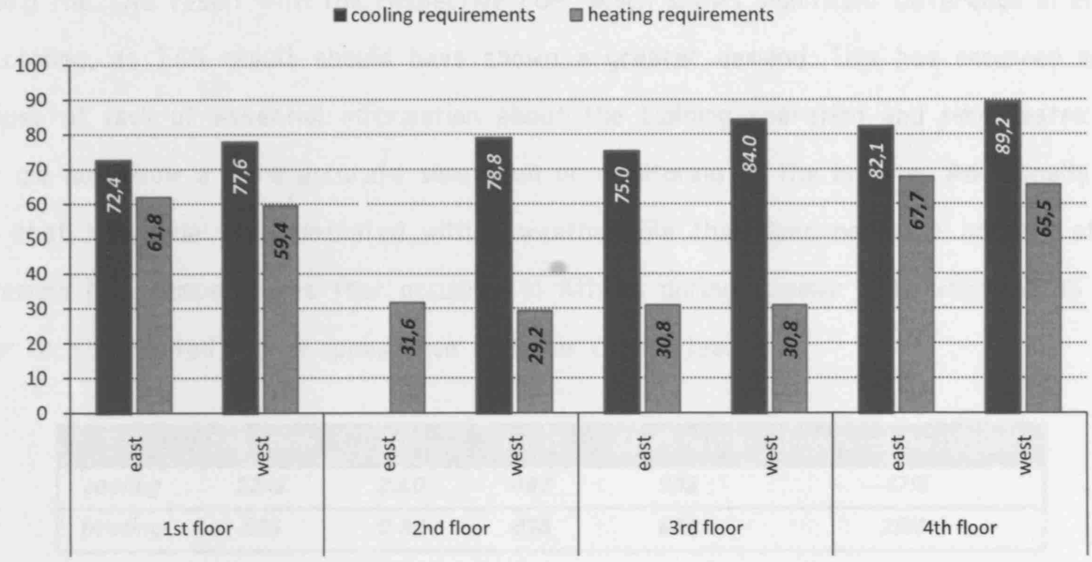


Graph 8: energy consumption for heating & cooling per unit area in relation to the floor (kWh/m^2)



Graph 9: energy consumption for heating & cooling per unit area in relation to the orientation (kWh/m^2)

The combined effect of the orientation and the level on the loads is illustrated on the next graph. In general, it should be pointed out that the most energy consuming areas of the building are the west side on the 4th floor for cooling loads and the east side on the 4th floor for heating. Intermediate floors appear more conservative in terms of energy consumption, which is quite expected as these floors are more protected against external conditions. More specifically, the cooling energy demand on the 4th floor rises up to 89.2 kWh/m^2 for the west side and 82.1 kWh/m^2 for the east, whereas on the 2nd floor these drop to 78.8 kWh/m^2 and 72.8 kWh/m^2 respectively. At the same time, heating loads reach the maximum value again on 4th floor and the minimum on the 2nd one. However, the most demanding part for heating is the east side with 67.7 kWh/m² followed by the west with 65.5 kWh/m². Likewise, on the 2nd floor the east side needs 31.6 kWh/m² and the west side 29.2 kWh/m².



Graph 10: energy consumption for heating & cooling per unit area in relation to the floor & orientation (kWh/m²)

In general, the results show that there is a great potential in savings in cooling loads as these far exceed heating loads. So, the potential improvements should mainly focus on the reduction of cooling loads. Additionally, these follow a linear increase in relation to the floors, whereas heating loads have a completely different distribution in relation to the floors. This indicates the fact that general improvements for reducing cooling loads in the whole building will be more effective, as heating loads, lower however, would require an approach differentiated and related to each floor. As far as the parameter of orientation is concerned, it does not influence loads as decisively as floor level.

It is important to notice that TAS results refer to energy output, whereas the BEMS data refer to energy input. So, in order to compare the different data of heating and cooling loads it is essential to convert the TAS results to loads of energy input. This is essential in order to estimate the reduction in CO_2 emissions that can be achieved by the upgrades that will be analyzed. In order to make this conversion, the ***Coefficient of Performance (COP)*** of the building services systems needs to be defined. The COP of a machine is the ratio of heat output to the energy needed to operate the machine (McMullan 2007).

Therefore, it is assumed that the COP for an air-conditioning system is 2.5 and for the oil boiler heating 0.8 (Young n.d.). The primary energy input can be then estimated when dividing the TAS result with the respective COP, which shows significant difference in energy for cooling, as TAS result should have shown a greater demand. This has occurred mainly because of lack of essential information about the building operation and time restrictions that did not allow a more accurate simulation or monitoring of the building. Additionally, the fact that the model was simulated with a weather file that does not take account of the extremely high temperatures that occurred in Athens during summer 2007 where BEMS data refer to, contributed to the appearance of lower cooling loads.

	TAS MWh	*COP*	*Input*	*BEMS MWh*	*Difference from BEMS*
cooling	***1242***	***2.50***	***497***	***932***	***-47%***
heating	***685***	***0.80***	***856***	***686***	***25%***

Table 10: differences between TAS and BEMS energy data

Taking account of the aforementioned analysis, the next chapter is going to explain how passive design improvements can enhance the building energy performance.

The main objective of chapter 5 is to investigate the potential improvements in the building envelope that can contribute to the more efficient control of solar gains. In other words, low-emissivity glazing and efficient shading are examined as measures that can result in lower energy requirements for heating and cooling.

Chapter 5: Delivering a sustainable future

5.1. Aims of energy-efficiency upgrades

Reduction in building energy consumption can be achieved mainly with upgrading the building envelope using passive means of sustainable design on the one hand and improving the nature and efficiency of the building services on the other. A building in the new era needs to regulate the climatic fluctuations during the whole year. Consequently, it is urgent for architects to develop building concepts, either for new or existing buildings, that have ***low heating energy requirements***, do ***not overheat in summer***, are provided with ***optimum levels of daylight*** and can be ***ventilated naturally*** (Richarz et al 2007). Accordingly, building conditioning requirements can be met with efficient installations that may include the implementation of renewable energy technologies.

When improving the energy performance of an existing building through major renovation, the ***Energy Performance of Building Directive (EPBD)*** must be taken into consideration. In the case study of the GSIS building which has a total useful surface of over 1,000 m^2, the energy performance has to be upgraded to meet minimum requirements based on Article 4 of the EPBD (Cibse 2003). According to this, the minimum energy requirements must be based on a methodology that takes account of the general indoor climate conditions avoiding possible negative effects. These requirements must be reviewed at least every five years (EU 2002).

Taking into consideration the theoretical framework set by the EPBD, the desired improvements can be made mainly by reducing heat gains installing shading devices and low emissivity (low-e) glazing and lowering artificial lighting requirements. Shading needs to protect building from overheating but simultaneously not obstruct visual comfort. In other words, their role is to minimise solar gains but also limit the time of closed mode to ensure maximum vision to the outside and the reduction of artificial lighting, allowing sufficient daylight to enter the interior. Simultaneously, low-e glazing can control more efficiently solar gains throughout the year.

5.2. Glazing

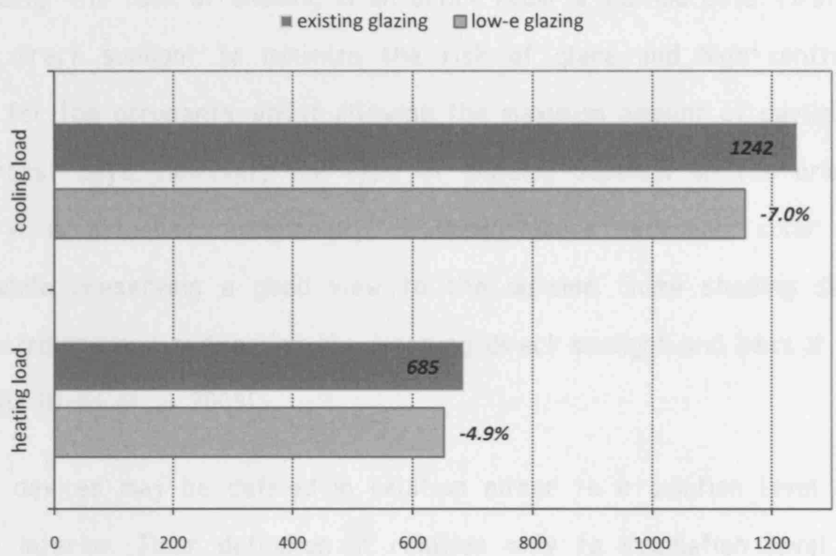
Glazing can contribute to the optimization of energy needs. Through thoughtful design, one which allows the building to take advantage of climatic and site conditions, windows can provide solar heating, day lighting, view and natural ventilation (UCL 2008). Glazing can also reduce noise and condensation problems. In general, the glazing performance is characterized by U-value, Solar Heat Gain Coefficient, visible transmittance and air infiltration.

Moreover, in terms of energy conservation improvements in the use of daylight and the lighting installations can contribute to the reduction of energy use. Some of the improvements related include the increase of the windows size, installation of reflective ceiling surfaces, use of sunshades to direct the light and illuminate the rooms according to requirements through rational space zoning (Richarz et al 2007).

In order to examine the potential impact of the improvements suggested, the TAS results can be the point of reference as qualitative data. So, the replacement of the existing poor-performing glazing with a modern low-e glazing can reduce the energy consumption. Analytically, the existing glazing (U-value = 5.458 W/m^2K) is replaced by a low emissivity glazing with U-value = 1.362 W/m^2K. The new Pilkington glazing consists of 6 mm kappafloat, 12 mm argon and 6 mm antisun.

Figure 44: performance of low-e glazing in cooling dominated climates

After simulating the TAS file, the results of the heating and cooling loads of the building are represented on graph 1. It is obvious that there is a significant reduction in both heating and cooling loads. Analytically, the reduction for the heating load approaches 4.9% and for cooling load the reduction rises to 7.0%. For the whole period of the year the total loads drop from 1964 MWh to 1807 Mwh (157 MWh), with the reduction approaching 8.0%.



Graph 11: impact of glazing on energy demands (MWh)

5.3. Shading

5.3.1 Aims of shading

Appropriate shading can prove beneficial when attempting to reduce energy consumption at an office building. The task of shading in an office room is multipurpose. First of all, shading should block direct sunlight to minimize the risk of glare and high contrasts which are discomforting for the occupants whilst allowing the maximum amount of daylight to enter the room on overcast days. However, the type of shading depends on the orientation of the building side it is attached. Additionally, it should block excessive solar gains to avoid overheating while preserving a good view to the outside. Some shading devices are also capable of controlling and redirecting the incoming direct sunlight and pass it on to the room as diffuse light (Hviid et al 2008).

Shading devices may be defined in relation either to irradiation level or temperature levels in the interior. Their definition in relation only to irradiation level may result to increase in energy for heating demand during the heating period because of obstructing solar gains in the interior. Likewise, taking account of the temperature levels only may result in the creation of dull spaces. However, the goal is to determine an efficient shading device based on the radiation level on the facade and the inside temperature (van Moeske et al 2005) in order to achieve the optimum results in energy conservation without sacrificing the interior space quality.

Since the south facade has already been equipped with horizontal shading devices it is essential to examine the characteristics of the optimum shading for the long east and west facades of the building. For this, according to Square One (2008), the following steps must be followed:

[1]. Determination of cut-off date, before which the window is to be completely shaded and after which the window needs to be only partially shaded

[2]. Determination of start and end times that represent the times of day between which full shading is required.

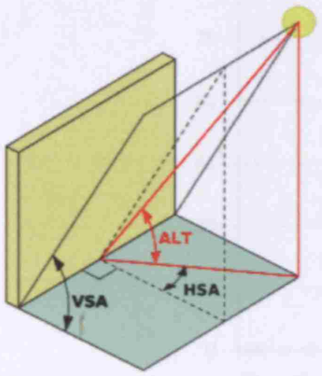
[3]. Looking up sun position using solar tables or a sun-path diagram to obtain the azimuth and altitude of the sun at each time on the cut-off date.

[4]. Calculation the Horizontal Shadow and the Vertical Shadow Angle.

[5]. Calculation of the required depth and width of the shading (Squ1 2008).

In the case of the GSIS building the chosen cut-off date is the day of the 21st September, i.e. the autumn equinox. The choice of this date is made under the assumption that the equinox signals the transition from the cooling period to the midseason period. In other words, it is the date after which the sun radiation becomes desired for the interior in terms of solar gain and daylight as the risk of glare is now reduced.

Furthermore, in order to design a shading device, it is essential to examine the required *Horizontal Shadow Angle (HSA)* and the *Vertical Shadow Angle (VSA)* which depend on the sun position and orientation of the window plane (figure 45). The HSA is the angle between the window pane and the azimuth of the sun and is relevant for vertical shading devices such as fins (Clear 2008). The VSA is important when designing horizontal shadings, whereas when designing east and west shadings HSA plays a more important role. The HSA and the VSA are represented on the following figure.



In general:

HSA = azimuth - orientation

VSA = arctan [tan(altitude)/cos(HSA)]

Figure 45: HSA and VSA

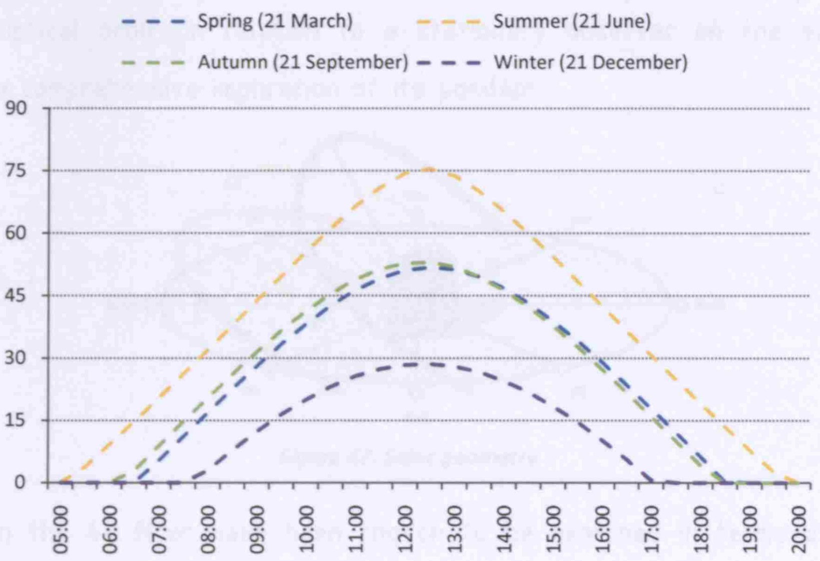
Although fixed solar shading systems perform well on a south facing facade, their performance is dramatically reduced on an east or west facing facade (Colt 2005). According to Cibse TM37 (2006), movable shading can respond to the solar demands of these facades because of their adaptability to the following parameters:

¬ *Seasonal requirements*: A controllable system allows the shading device to follow the sun path optimizing its performance as it minimizes heat gains in summer whilst maximizing solar gain during winter when it can be fully-opened.

¬ *Daily weather*: Likewise, a controllable system can be adjusted during dull days when shading is not desired.

¬ *Occupant requirements*: Occupants may require extra privacy for some activities or extra control of glare.

The shadings need to be designed under the assumption that full shading is desired between 1st May and 21st September, i.e. the cooling period, and basically on a daily basis from 10 a.m. to 5 p.m. However, since the sun path is symmetrical in relation to the solstices, when taking account of sun angles for the autumn equinox, then the shading will cover the respective building facade from spring equinox till autumn equinox. This involves the danger of causing an increase in heating loads due to unwanted shading during spring when external temperature has not risen significantly and the building is not heated up from the prior cool winter period.



Graph 12: Sun path diagram of the sun altitude for Athens, Greece

Graph 12 shows the sun path during the four critical dates of the year. The sun path varies throughout the year, i.e. the longest sun path occurs in summer and the shortest in winter, which means that different elevations of a building are affected at different times of the year. Additionally, the sun angle varies throughout the year. For instance, the sun at noon in summer is at 75.5° and in winter at 28.6°.

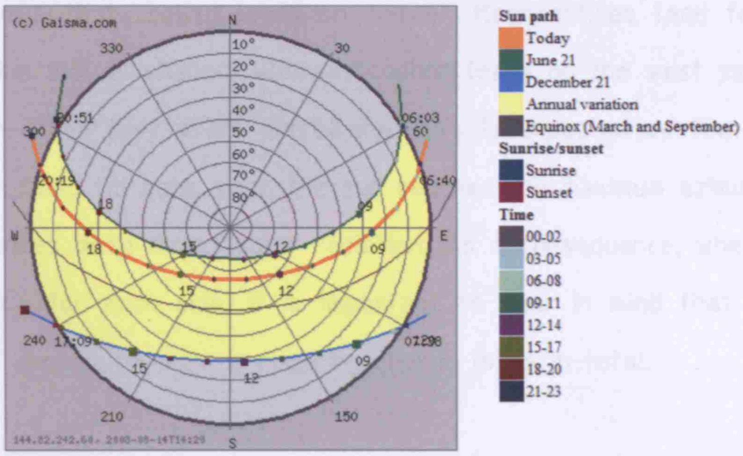


Figure 46: Sun path diagram of the sun azimuth for Athens, Greece

In order to prevent the risk of unwanted shading, it is essential to regulate the function schedule of the shading, so that it comes into effect only after May. In this framework, the critical sun angles are observed on 21st June and 21st September. Analytically, at 12 p.m., on 21st June, the sun achieves its highest position on the sky (altitude 74.4°, azimuth 156.4°) and at 9 a.m., on 21st September, achieves its lowest position (altitude 31.5°, azimuth 116.8°) during the respective cooling period. But since the sun moves around the earth in an elliptical orbit (in relation to a stationary observer on the earth), the VSA provides a more comprehensive implication of its position.

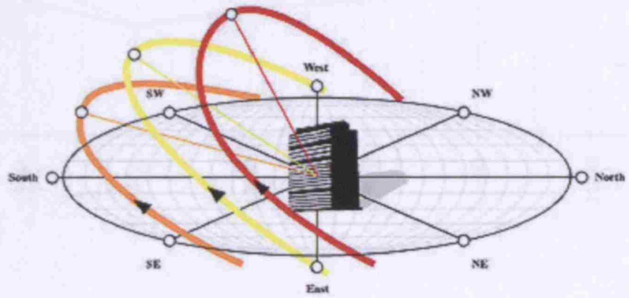
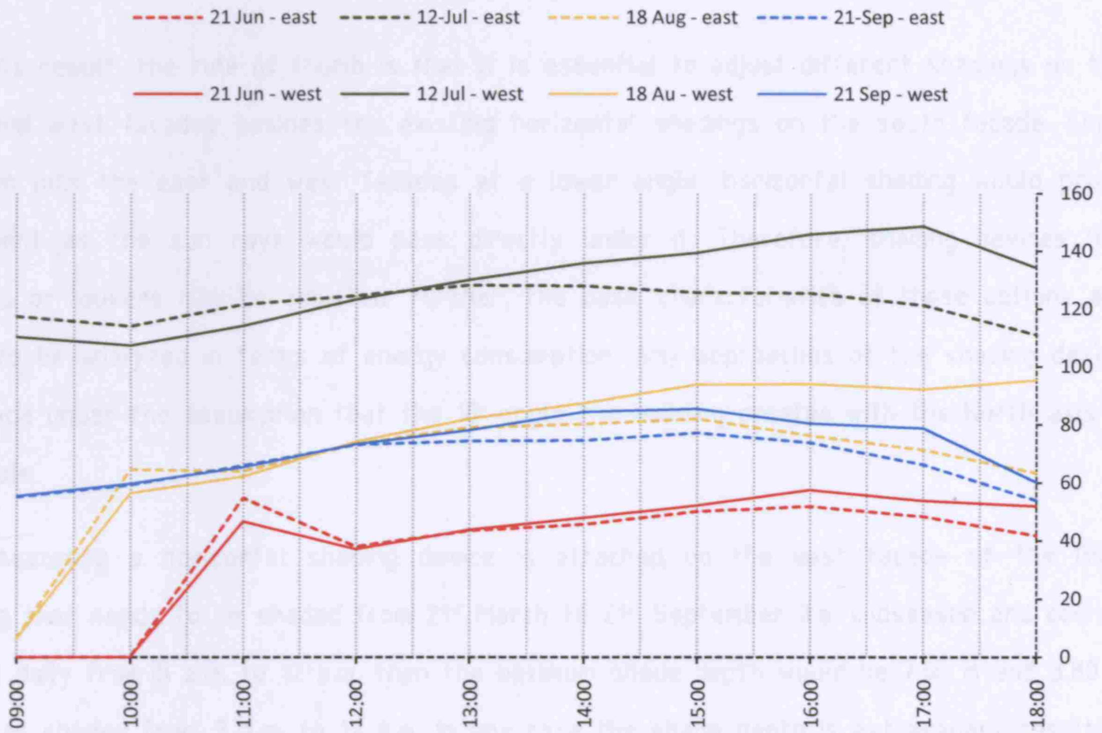


Figure 47: Solar geometry

Offices on the 4th floor have been chosen to be examined in terms of cooling loads because, as previously stated, they are the most energy demanding offices of the building. Therefore, they will be used as a case study in order to examine the potential savings due to efficient shadings. Cooling loads are going to be analyzed during four critical dates of the cooling period: 21st June (summer solstice), 12th July (the warmest day of the year), 18th August (a typical summer day) and 21st September (autumn equinox and end of the cooling period).

Graph 13 shows that cooling loads on the 4th floor offices tend to decrease in the afternoon, when this side is shaded, whereas cooling loads on the west side keep increasing until around 4 p.m. when they start decreasing. This is expected as the sun heats up the east side of the building till noon when the sun reaches the maximum azimuth and after then the west side receives more direct solar radiation. As a consequence, when trying to define the optimum shading for each side, it is important to bear in mind that an efficient west shading device will contribute more in reducing cooling loads in total.



Graph 13: cooling loads at 4th floor during critical dates per unit area (Wh/m^2)

In terms of solar performance, figure 48 shows that for both east and west facades the sun is higher during noon lowering either at the start of the day for the east façade or at the end of the day for the west façade. Similarly, the sun path in winter is shorter than in summer. However, it is important to notice that the minimum angle sun rays hit the window appears at the end of the day and not in the morning, when the sun rises at a higher position.

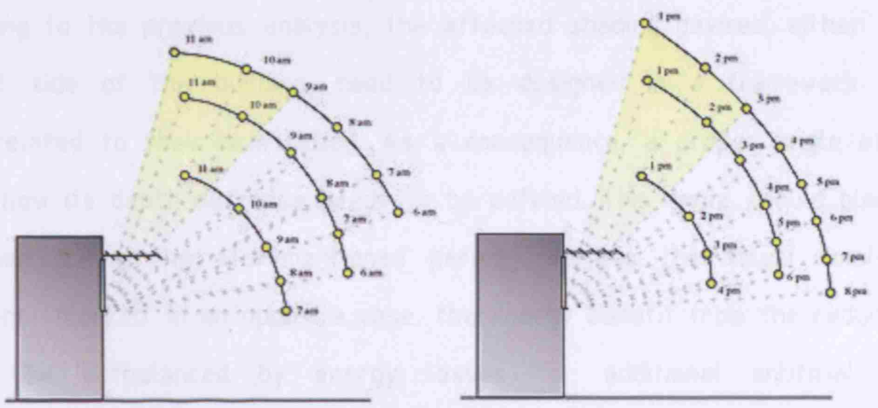


Figure 48: East and west facing facades with horizontal shading

As result, the rule of thumb is that it is essential to adjust different shadings on the east and west facades besides the existing horizontal shadings on the south façade. Since the sun hits the east and west facades at a lower angle, horizontal shading would prove inefficient as the sun rays would pass directly under it. Therefore, shading devices like awnings or louvers may be adjusted. Further, the basic characteristics of these options are going to be analyzed in terms of energy consumption. Any approaches of the shading design are made under the assumption that the 10° angle the building creates with the North axis is negligible.

Assuming a horizontal shading device is attached on the east façade of the GSIS building that needs to be shaded from 21st March to 21st September (i.e. midseason and cooling period) daily from 8 a.m. to 12 p.m. then the optimum shade depth would be 7.60 m and 3.80 m if it was shaded from 9 a.m. to 12 p.m. In any case the shade depth is extravagant resulting in an enormous element with various functional and architectural drawbacks.

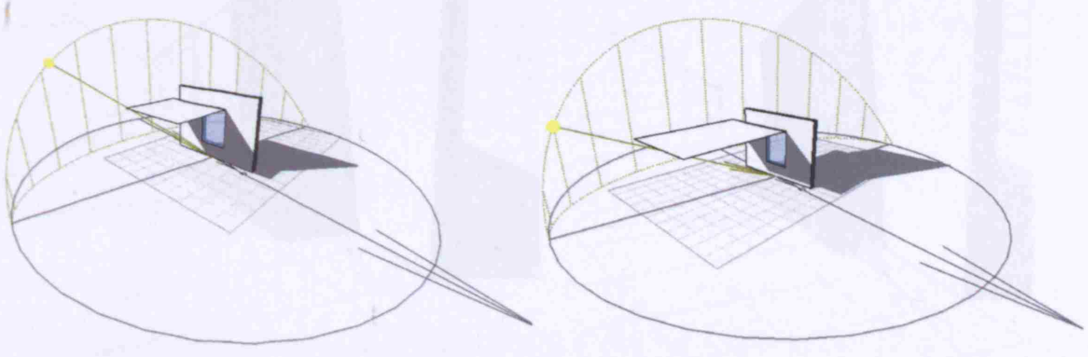


Figure 49: Optimum shading (21st September) at (i) 8 a.m. and (ii) 9 a.m.

According to the previous analysis, the attached shading devices, either for the east or the west side of the building, need to be designed in a framework of different approaches related to their orientation. As a consequence, a proper angle of the awning that would allow its depth decrease needs to be defined. This angle should block the direct solar radiation during the aforementioned period, whereas the visual comfort and the daylight are not blocked. In an opposite case, the energy benefit from the reduction of solar gains would be outbalanced by energy losses for additional artificial lighting and deterioration of interior space qualities. Consequently, two different awnings for each side are tested on the TAS model:

5.3.2 East shading (awning at 30°/40°)

East Feature shade		**30°**	**40°**
Surface	*Height (m)*	**2.40**	**2.40**
	Width (m)	**1.00 – 4.00**	**1.00 – 4.00**
Overhang	*Depth (m)*	**2.60**	**2.30**
	Offset (m)	**-1.50**	**-1.90**
	Transmittance	**0.50**	**0.50**

Table 11: east feature shades

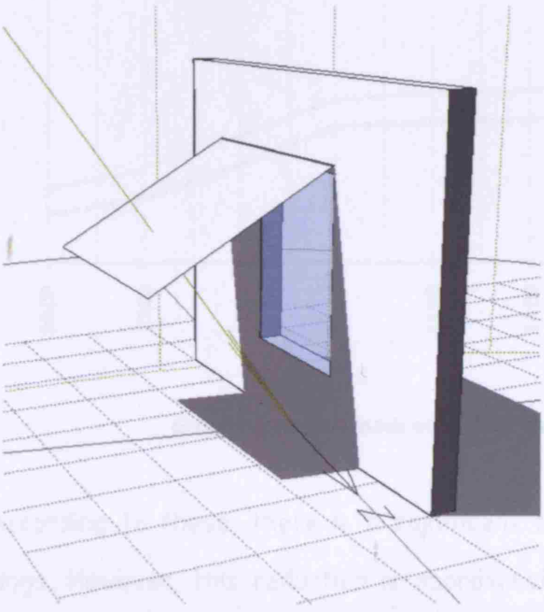


Figure 50: east awning at 30 °C

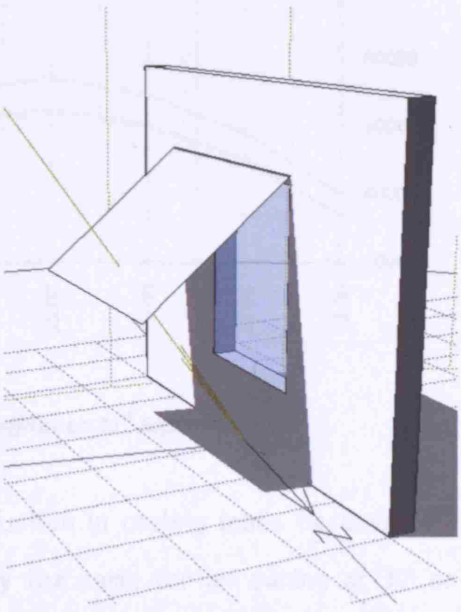
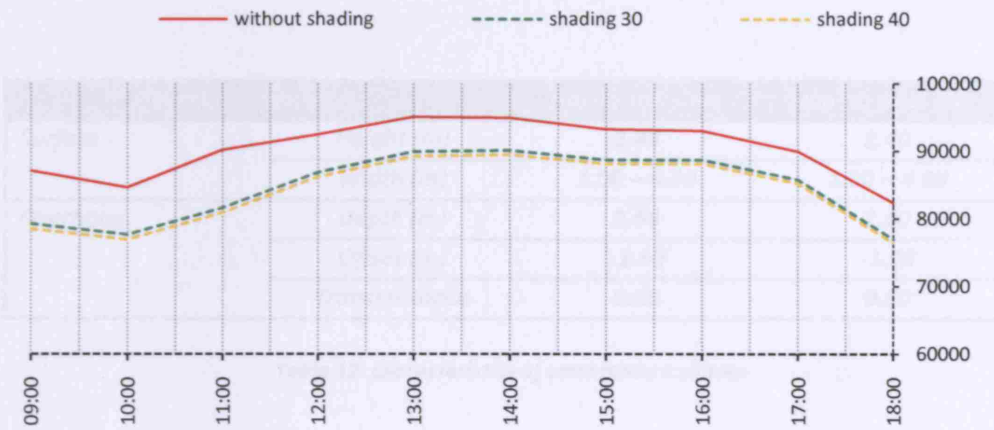


Figure 51: east awning at 40 °C

The awnings have been attached to the four different (regarding their width) east window panes during the midseason and the summer. The effects of the two different awnings are presented at graphs 14 and 15 which represent the reduction in cooling loads at the 4th floor east offices during July 12th (the warmest day according to the weather file) and September 21st (the end of the cooling period).



Graph 14: cooling loads at 4th floor east offices on 12th July (W)

Graph 15: cooling loads at 4th floor east offices on 21st September (W)

According to these, there is a significant reduction in cooling loads because of the use of awnings. However, this reduction is approximately the same for an awning at 30° or at 40° on July 12th, approaching 6.3% for the first and only 0.8% further reduction resulting in a total 7.1% for the latter. The corresponding percentages for September 21st are 8.0% and

9.2%. At the same time the daylight factor is significantly reduced with an awning at 40° during all the shading period. Therefore, an east awning at 30° may be preferable, as it contributes considerably to energy conservation whilst it preserves a satisfactory daylight factor level for the interior.

5.3.3 West shading (horizontal/vertical slats)

West Feature shade		Horizontal slats	Sloping slats (30°)
Surface	Height (m)	2.40	2.40
	Width (m)	1.00 – 4.00	1.00 – 4.00
Overhang	Depth (m)	2.60	2.30
	Offset (m)	-1.50	-1.90
	Transmittance	0.50	0.50

Table 12: characteristics of west feature shades

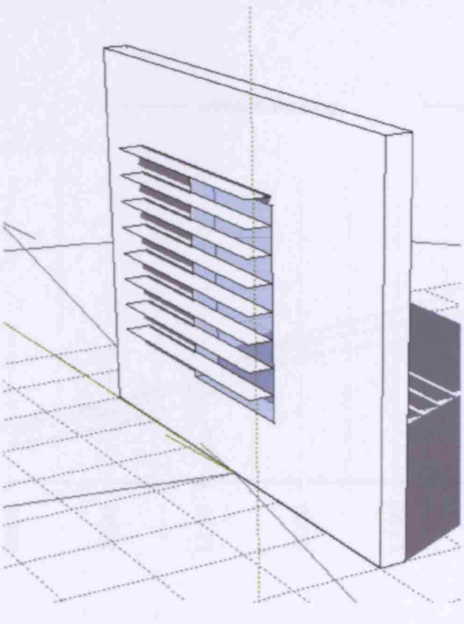


Figure 52: west horizontal slats

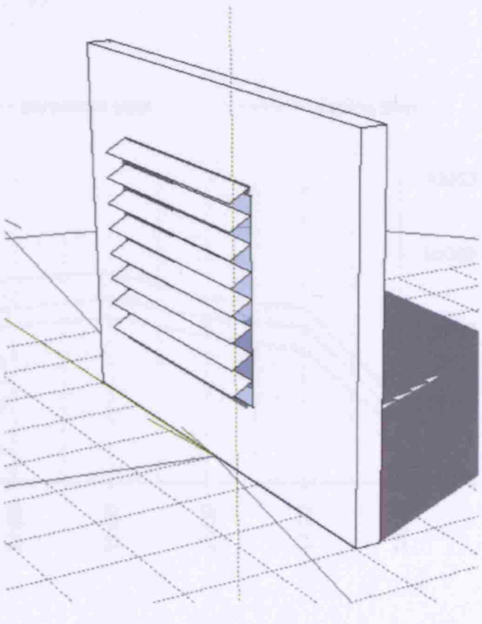
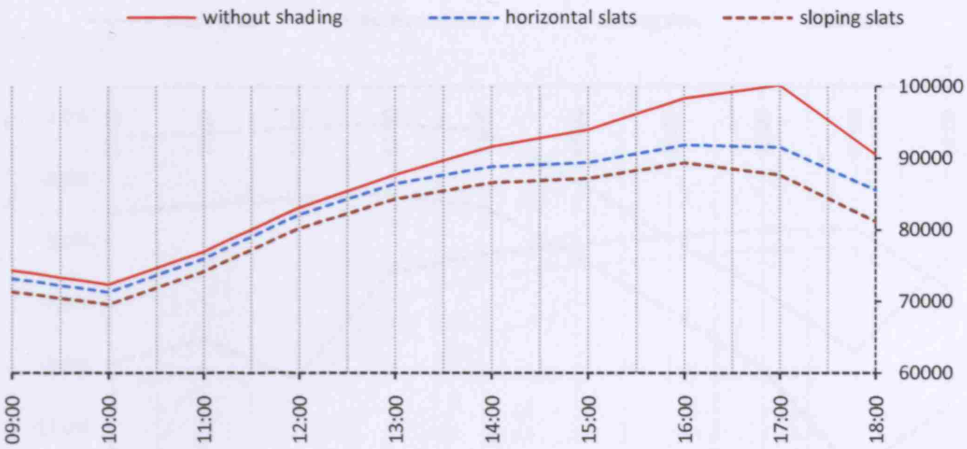
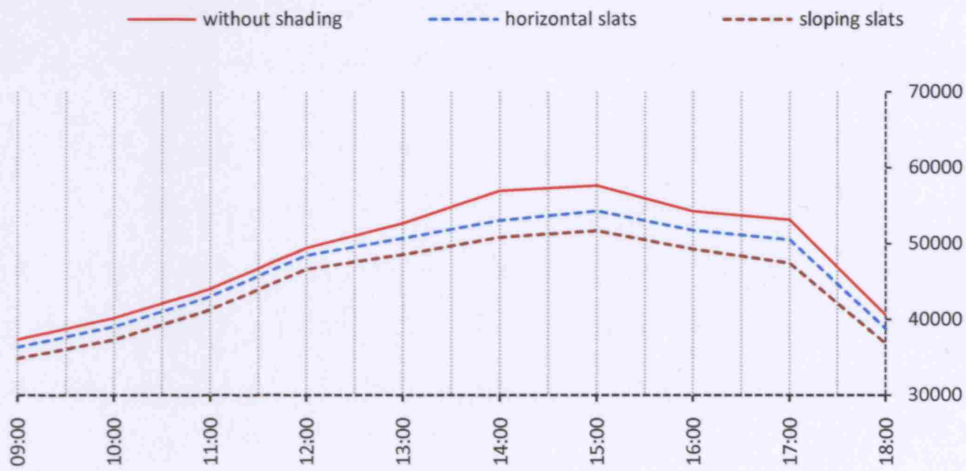


Figure 53: west sloping slats at 30°

As far as the west shading device is concerned, its beneficial effect becomes more tangible in the afternoon, when that part of the building receives direct solar radiation. In general, on July 12th the total reduction in cooling loads approaches 3.8% in the case of horizontal slats and 6.6% in the case of sloping slats. Accordingly, on September 21st, the reduction is 4.2% and 8.5% respectively. The total reduction in cooling loads at the west offices of 4th floor for the whole cooling period is 4.9% and 9.8% for horizontal and sloping slats respectively.

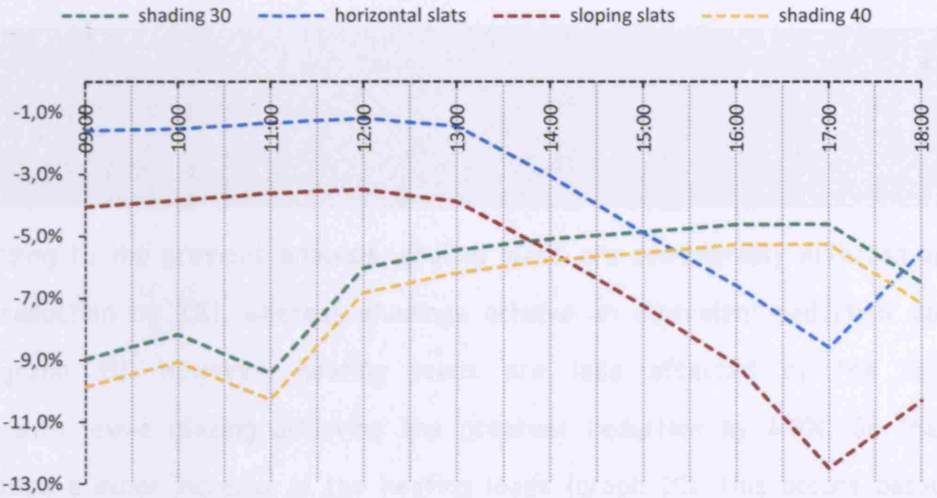


Graph 16: cooling loads at 4th floor west offices on 12th September (W)



Graph 17: cooling loads at 4th floor west offices on 21st September (W)

However, it should be noticed that the greater savings from west shading devices appear in the afternoon, with a maximum at 5 p.m. with a reduction of 12.5%, as in the morning the reduction in cooling loads is considerably lower. Likewise, in the morning the east shadings perform better resulting in lower cooling demands reaching their maximum efficiency at 11 a.m. with a reduction in cooling loads of 10.3%. When comparing the efficiencies of the east and west shadings it is important to notice that although west shadings improve their efficiency to a large extent in the afternoon (large fluctuations in reduction of cooling demand from 1.2% to 12.5%), the east shadings have a more stabilized efficiency during the whole day, since the reduction in cooling loads fluctuates between 4.6% and 10.3%.



Graph 18: reductions in cooling loads achieved with improvements at 4th floor offices on July 12th (%)

5.4. Discussion on the combined effect of improvements

Taking account of the previous analysis of upgrading the building envelope, the optimum improvements that can enhance its energy performance are the following:

[1]. Low-e glazing

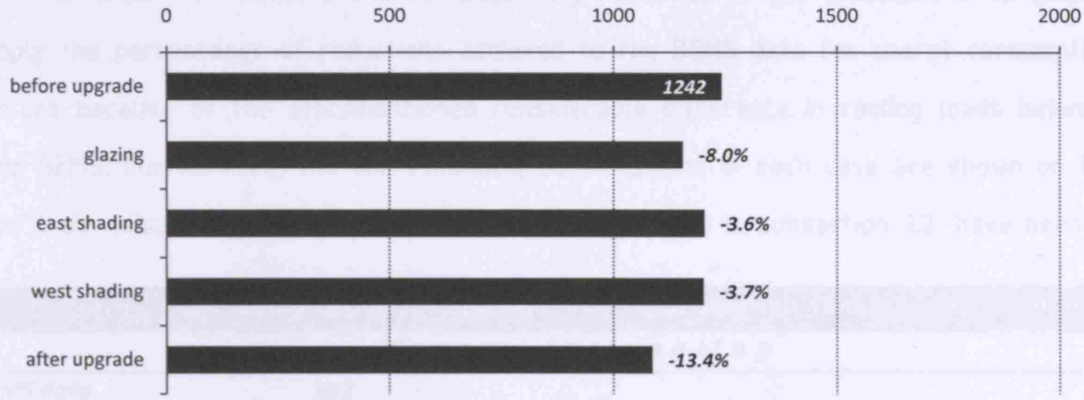
[2]. East awning at 30° angle and

[3]. West sloping slats at 30° angle

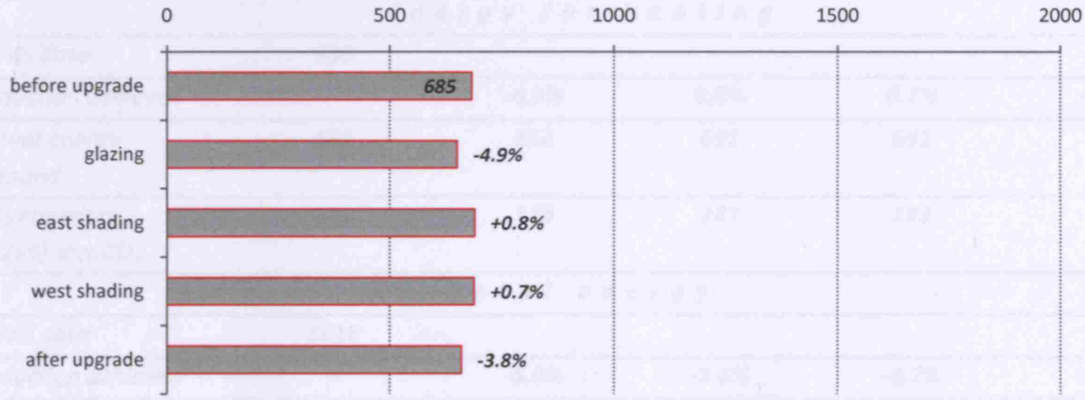
According to the previous analysis, cooling loads are considerably affected by the low-e glazing (reduction by 7%), whereas shadings achieve an equivalent reduction varying from 3.1-3.3% (graph 19). However, heating loads are less affected by the improvements suggested, with low-e glazing achieving the greatest reduction by 4.9%. On the contrary, shadings cause a minor increase in the heating loads (graph 20). This occurs because of the fact that shadings block the desired solar gains that heat up the interior space during cooler days of the midseason. In order to avoid this risk it would be essential to install an automated mechanism that would turn the shadings off in case of unexpected temperature drop or during dull days, so as to avoid undesired increase in heating demand.

In general, the most effective improvement according to the TAS simulation results is the replacement of the existing glazing with the modern low-e glazing. This decreases annual energy demand for heating and cooling by 8.0%. East and west shading achieve a reduction by 3.6 and 3.7% respectively. When applying all the improvements the reduction in cooling loads approaches 13.4% and in heating 3.8%, achieving a total reduction in energy consumption by 11.9% or 216 MWh (graph 21).

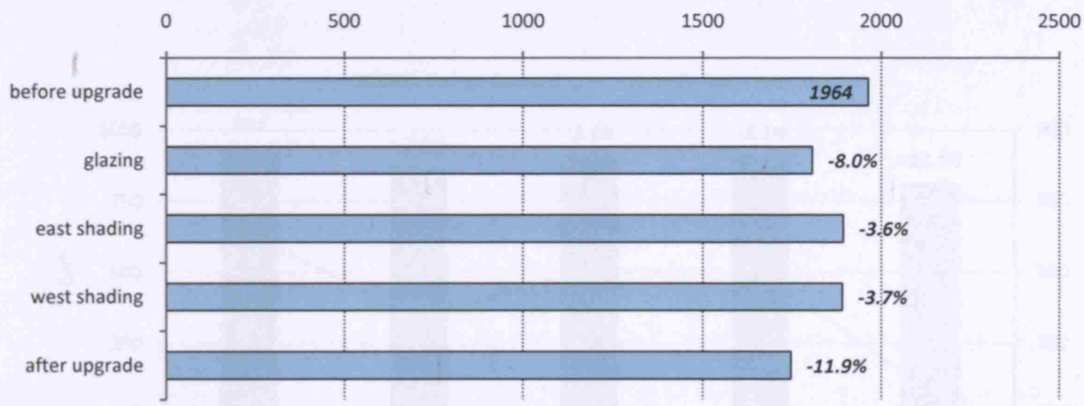
However, the reduction in cooling loads (13.4%) far exceeds the reduction in heating loads making the previously analyzed improvements beneficial mainly during the cooling period. The latter is of major significance in Mediterranean countries, where due to climate change and global warming cooling needs tend to rise continuously, whereas heating demands decrease.



Graph 19: effects of improvements on annual cooling loads (MWh)



Graph 20: effects of improvements on heating loads (MWh)

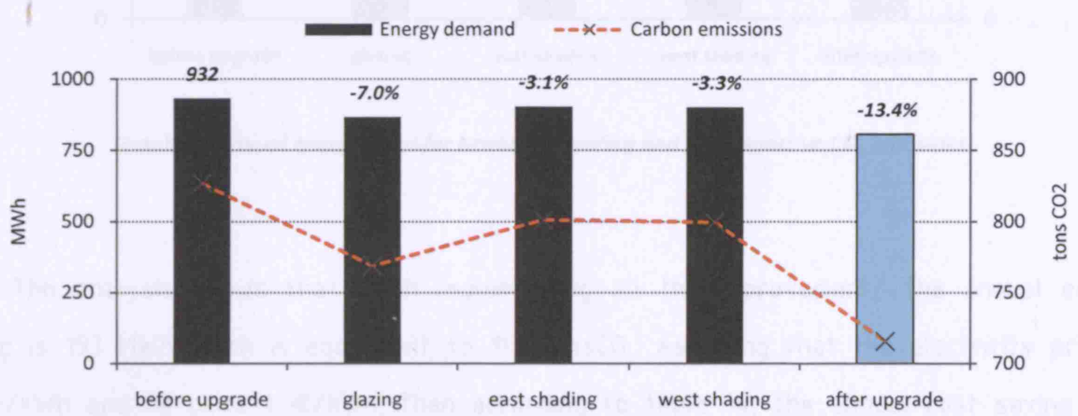


Graph 21: effects of improvements on heating & cooling loads (MWh)

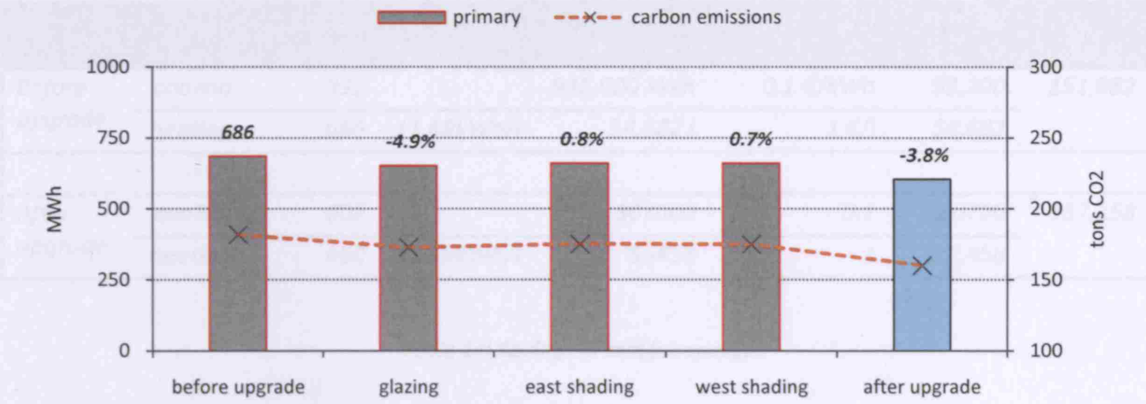
In order to calculate the corresponding reduction in CO_2 emissions it is essential to apply the percentages of reductions achieved to the BEMS data for energy consumption. This occurs because of the aforementioned considerable difference in cooling loads between TAS and BEMS. Furthermore, the corresponding CO_2 emissions in each case are shown on table 13. For their calculation, the emissions factors, as described in subsection 3.2, have been used.

	before upgrade	glazing	east shading	west shading	after upgrade
		Energy for cooling			
BEMS data	*932*				
Reduction achieved	*--*	*-7.0%*	*-3.1%*	*-3.3%*	*-13.4%*
Actual energy demand		*867*	*903*	*901*	*807*
CO_2 emissions – (0.887) tonsCO_2	*827*	*769*	*801*	*799*	*716*
		Energy for heating			
BEMS data	*686*				
Reduction achieved	*--*	*-4.9%*	*0.8%*	*0.7%*	*-3.8%*
Actual energy demand	*686*	*652*	*691*	*691*	*660*
CO_2 emissions – (0.265) tonsCO_2	*182*	*173*	*183*	*183*	*175*
		Total energy			
BEMS data	*1618*				
Reduction achieved	*--*	*-8.0%*	*-3.6%*	*-3.7%*	*-11.9%*
Actual energy demand		*1489*	*1560*	*1558*	*1425*
Total CO_2 emissions - tonsCO_2	*1008*	*942*	*984*	*982*	*891*

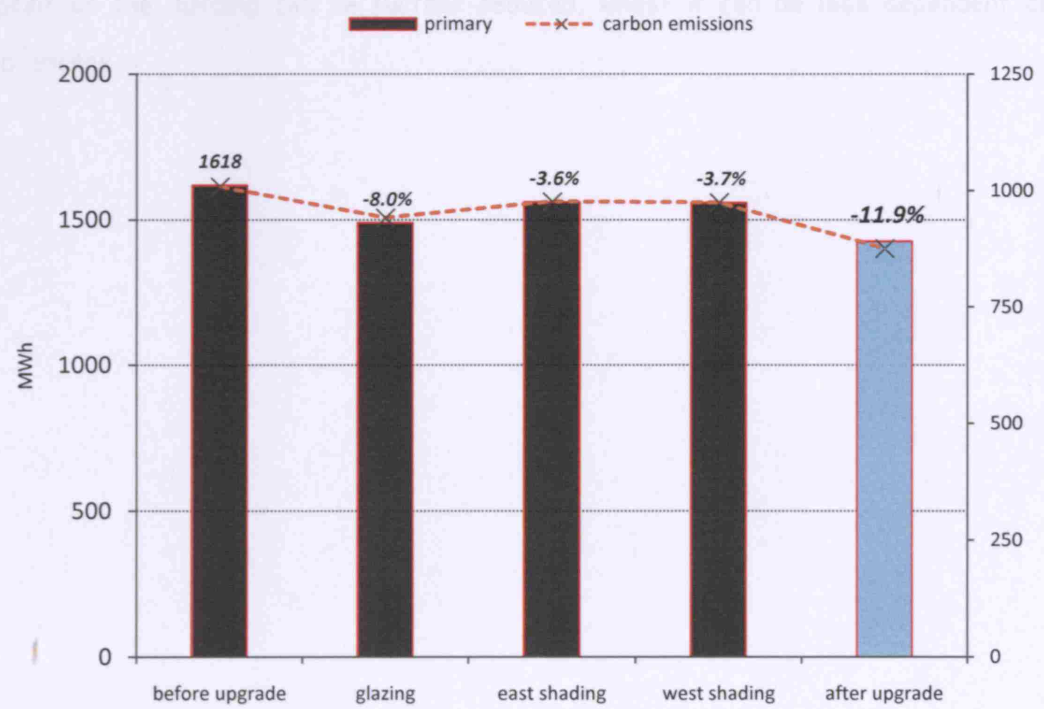
Table 13: effect of improvements on actual energy consumption (MWh)



Graph 22: annual energy input for cooling and the respective CO_2 emissions



Graph 23: annual energy input for heating and the respective CO_2 emissions



Graph 24: annual energy input for heating & cooling and the respective CO_2 emissions

The analysis shows that when implementing all the improvements the annual energy saving is 193 MWh which is equivalent to 117 $tonsCO_2$. Assuming that the electricity price is 0.1 €/kWh and oil price 1 €/kWh, then according to table 14, the annual cost saving from the improvements is € 14,724 which is equivalent to 14,724 / 117 = 126 €/$tonsCO_2$.

		Energy (MWh)	Conversion factor	Energy	Cost of fuel	Cost (€)	Total cost (€)
Before upgrade	*cooling*	*932*		*932,000 kWh*	*0.1 €/kWh*	*93,200*	*151,882*
	heating	*686*	*11.69kWh/l*	*58,682 l*	*1 €/l*	*58,682*	
After upgrade	*cooling*	*807*		*807000*	*0.1*	*80700*	*137,158*
	heating	*660*	*11.69kWh/l*	*56458*	*1*	*56,458*	

Table 14: Savings in cost for energy

The following chapter is going to analyze the potential of implementing renewable energy technologies in order to generate zero-carbon electricity. By this way, the carbon footprint of the building can be further reduced, whilst it can be less dependent on fossil-based energy.

When examining energy-efficiency upgrades for an existing office building, the implementation of renewable energy becomes essential. The application of Photovoltaics for the generation of zero-carbon electricity can make the building less dependent on fossil-based energy.

Chapter 6: Application of Photovoltaics

6.1. Zero-carbon electricity

After the primary building renovation in 2007 nineteen ***photovoltaic (PV)*** panels, covering a total area of 25.8 m², were installed in order to generate electricity. These PV panels have a peak power of 3.325 kW and have been installed facing south at a 30° angle. The energy generated is supplied parallel to the national grid to the lighting installations and auxiliary systems of the third and fourth floor of the building. It is obvious that the amount of energy generated from these PVs is only a minor fraction of energy compared to the total annual building demands.

However, in terms of delivering a sustainable future for the building and adapting it to the new era it is essential to reduce its dependence on grid supplied electricity. The dependence of energy demands on fossil-based electricity has been repeatedly blamed for the global warming. When coal, gas and oil are burnt, they release harmful gases, which trap solar radiation in the atmosphere and cause global warming (Omer 2006). Renewable energy technologies can contribute to the reduction of use of fossil fuels and enable a sustainable future in the building sector.

Figure 54: PV installation

What is renewable energy? Renewable energy is energy that, in its production or consumption, has no impacts on the environment; it is a sustainable form of energy, which has attracted more attention during recent years (Omer 2006). In this context, one of the fundamental forms of renewable energy is energy generated from PV panels. Although solar energy has been harnessed for thousands of years, photovoltaic cells are a relatively modern technology. These systems use solar cells to convert sunlight into electricity (CIBSE TM38 2006).

A brief description of how PV cells operate might be useful. The PV cell consists of one or two layers of a semi-conducting material, usually silicon. When light shines on the cell it creates an electric field across the layers, causing electricity to flow; the greater the light intensity, the greater the flow of electricity. There are three basic kinds of solar cells:

¬ monocrystalline: which has a typical efficiency of 15%

¬ polycrystalline: which has a typical efficiency of at least 13%

¬ thin film: which can be applied to other materials such as glass or metals and has a typical efficiency of 7% (CIBSE TM38 2006).

6.2. PV selection and payback period

The selection of the PV has been made under the following assumptions:

- The total available area on the roof for the system installation is: 119 x 39 = 4,485 m^2 reduced by approximately 10% due to other installations, which means that the total available area for the installation of PV panels is 4,000 m^2.

- The optimum orientation is the south at an inclination smaller than the latitude (37.9°) in order to take advantage of the solar radiation in summer. So, an inclination of 30° is preferred.

- Polycrystalline PV panels are chosen. These are less efficient than monocrystalline, however they are less expensive.

- According to HELAPCO (2008) the cost for a PV installation in Greece varies from 5-5.5€/W_p. So, for a PV installation of 492,000 W_p the cost is 5.5 x 492,000 = € 2,706,000.

- Of the aforementioned amount 40% is subsidized (Helapco 2008), so the investment cost is 2,706,000 x 60% = € 1,623,600

- The operational and maintenance costs of a PV installation approaches in average 1% of the initial cost investment cost per year, which is 2,706,000 x 1% = 27,060 €/year.

- The 431,000 kWh of electricity generated annually by the PV systems are sold to the national grid at the price of 0.50 €/kWh.

- However, this amount of electricity is replaced by the grid at the price of 0.10 €/kWh (Dei 2008). As a result, the profit from each kWh generated is 0.50 – 0.10 = 0.40 €/kWh.

- The annual saving is 431,000 x 0.40 = 174,400 €/year.

- Subtracting for this amount the operational cost, then the net income is 147,340 €/year.

¬ The latest inflation rate in Greece has been 4.9% (Eurostat 2008).

RETScreen 4.0 has been used in order to evaluate the energy production from the PV panels. The installation of the PVs aims at the generation of electricity equivalent to 10% of the total energy consumption (4,902 MWh). Therefore, the required amount of energy to be generated is 490 MWh. So, installing 4,000 Sharp PV panels (poly-Si-ND-L3EJE) 431 MWh of electricity will be generated, which is equivalent to 371 tonsCO_2 not released to the atmosphere. In this case the payback period will be 18.6 years (App. Figure 72).

If estimating the payback period with the use of the discount flow analysis method, then this is 17 years (App. Figure 73). This payback period was calculated under the assumption that the electricity generated is sold to the grid at the price for energy generated from PVs (0.50 €/kWh) and bought back from the grid at the normal price (0.10 €/kWh). However, this cannot occur under the current legislation, as electricity generated from PVs can be sold to the grid at the high price only if the generated energy covers the total building energy requirements, which does not take place in the case of the GSIS building. So, when trying to establish a framework encouraging for the implementation of renewable energy technologies it is essential to bear in mind that zero-carbon electricity is vital for climate protection and accordingly, it could be generated under a more environmental scope rather than merely economic. Especially, at office buildings of the public sector in Greece part of the energy required should be generated from PVs offering the incentives for a more general application of PVs in large-scale building.

The case of the expensive zero-carbon energy is similar to the case of the mobile telephony. Although the cost of using a cellular is significantly higher than using a landline, the use of cellular has become widespread due to the high quality communication they offer. Similarly, zero-carbon electricity is high-quality energy that enables a sustainable future for the Earth.

Chapter 7: Conclusions

Climate change and global warming demand instant action. And as buildings are responsible for almost half of the energy use, then the energy upgrade of existing buildings is of major significance in the new era. As buildings become older they tend to have incremental energy requirements. Undertaking the GSIS building as a case study has resulted in conclusions on three consecutive levels.

a. passive design techniques

The implementation of passive design techniques that control solar gains is of major significance. They can reduce the energy demands of the buildings, whilst maintaining a high level of indoor air quality. Additionally, they contribute to the reduction in GHGs emissions, which is the basic target of sustainable design in the combat against climate change. Therefore, appropriate shading and glazing are the most important energy efficiency upgrades for a building. Control of solar gains with shading and glazing can reduce energy consumption by a total of 11.9%, or 3.8% for heating and 13.4% for cooling. Taking account of the previous upgrade of the building which had included additional insulation and south shadings and had led to a reduction in energy use by 31.3%, then it is obvious that the impact of upgrading the building envelope becomes crucial.

b. systems efficiency

The energy efficiency upgrade of an existing building can reduce the demands in energy for heating and cooling. However, because energy loads are closely related to the building services systems that offer heating ventilation or cooling, it is important to improve their efficiency. More efficient building services need less energy input to produce the same output. In combination with reduced output needs due to lower loads required because of the first level upgrade, then the positive effect is multiplied. So, it is important to improve the boiler efficiency from 0.8, which is currently, to 0.9 and the air conditioning from 2.5 to 3.0. The enhancement of systems efficiency can accordingly reduce heating loads by 11.2% and cooling loads by 16.8%. In the case of the GSIS building this would mean the saving of additional 74 MWh from heating and 135 MWh in cooling. In total, 209 MWh could be saved annually, which would cause a further reduction in energy use for heating and cooling by 14.2% rising up to 25% in relation the energy demands prior to the upgrades of the first two levels.

c. zero-carbon electricity

The impact of enabling renewable energy technologies in an existing building is beneficial for the environment as in this way energy is generated at no carbon emissions. The installation of PVs at the roof area can generate an amount of electricity that is equal to 10% of the total annual building energy demands. However, the most important aspect of the implementation of renewable energy sources is its economic feasibility. This relies on the availability of the system to supply part of the generated electricity to the national grid because the price for each kWh sold is significantly increased in that case. In an opposite occasion, the economic feasibility of PV installations may be vague because of the finite system ability to generate electricity. In that case the idea of enabling renewable energy sources for supplying the building energy demands should be reviewed under a more environmental scope rather than merely economic. In this context, generating electricity from PVs, expensive though, it will be challenging and beneficial since its contribution to the combat against climate change will be determinative.

In general, a successful energy-efficiency upgrade of an existing office building relies on the interconnection of the three levels of improvements. Firstly, it is the passive design techniques that can enhance permanently the building energy performance making it more autonomous. Secondly, it is the improvement of the building services systems efficiency so that they achieve the same performance at lower energy demands. Thirdly, it is the implementation of alternative energy sources to supply the energy demands of the building reducing its dependence on fossil-based energy. Therefore, the basic aims of study have been achieved and the positive effects of the upgrade can be extended depending on the proper operation and energy management of the building. However, due to the limited available time for this dissertation, the potential of natural ventilation, which would have caused the restructuring of the interior space was not examined although it would have brought up effective reductions in energy use.

But the most important is the well-educated employees who will make sensitive use of the services being conscious that being extravagantly demanding in thermal comfort or irrational use of lighting results in excessive energy use and even greater increase in CO_2 emissions. Increasing the upper limit of the thermostat by 1 °C during the cooling period brings up a decrease in CO_2 emissions associated with cooling by 19%.

Finally, the impact of energy efficiency upgrades in office buildings in Greece will be very effective. Not only is the use of energy reduced, with all the financial consequences, but the protection of environment is enhanced. Especially, it the context of the Kyoto Protocol and the poor performance of Greece in reducing GHGs emissions, energy efficiency upgrades must be promoted from the state by establishing a sustainable framework. In other words, the extent of the upgrades effectiveness will be influenced by the appropriate legislation that needs to come in force urgently along with the implementation of the EPBD. In an opposite occasion, the quality of the built environment will be further deteriorated because of eruptive increase in energy use in order to correspond to the more demanding thermal comfort levels.

Chapter 8:Appendix

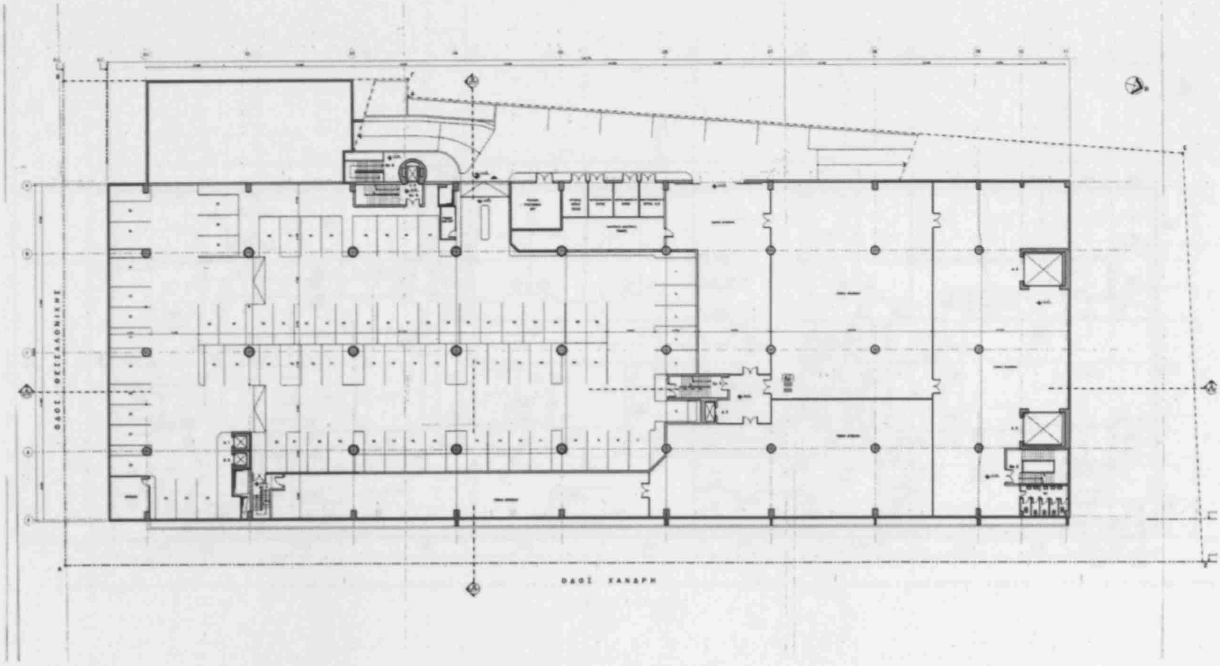


Figure 55: basement

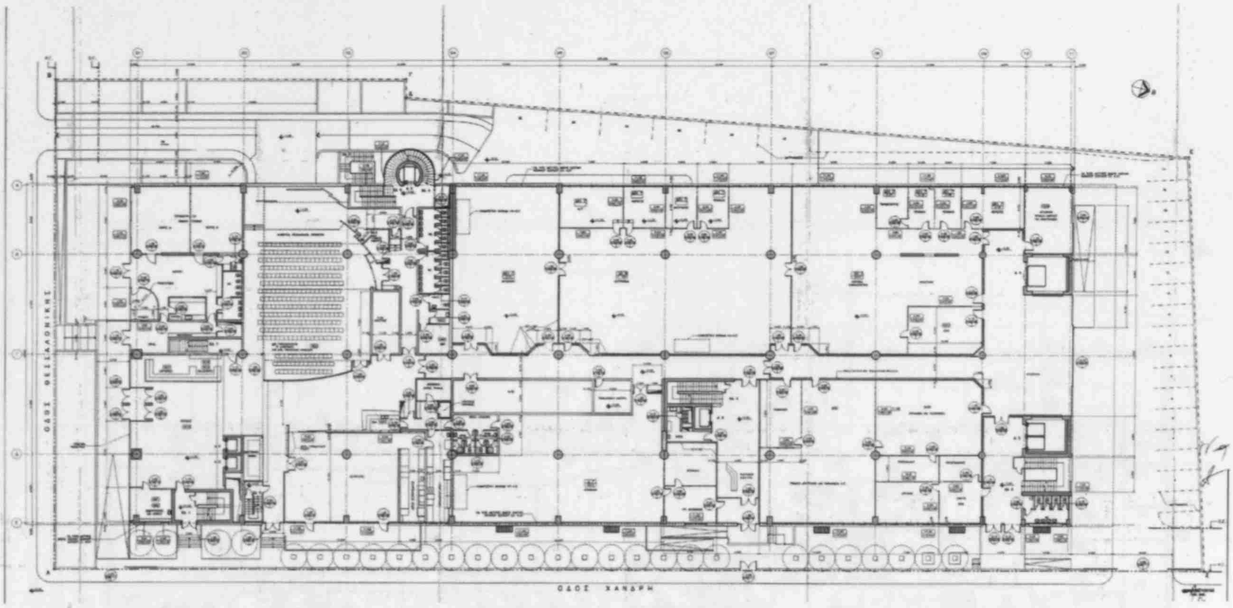


Figure 56: ground floor

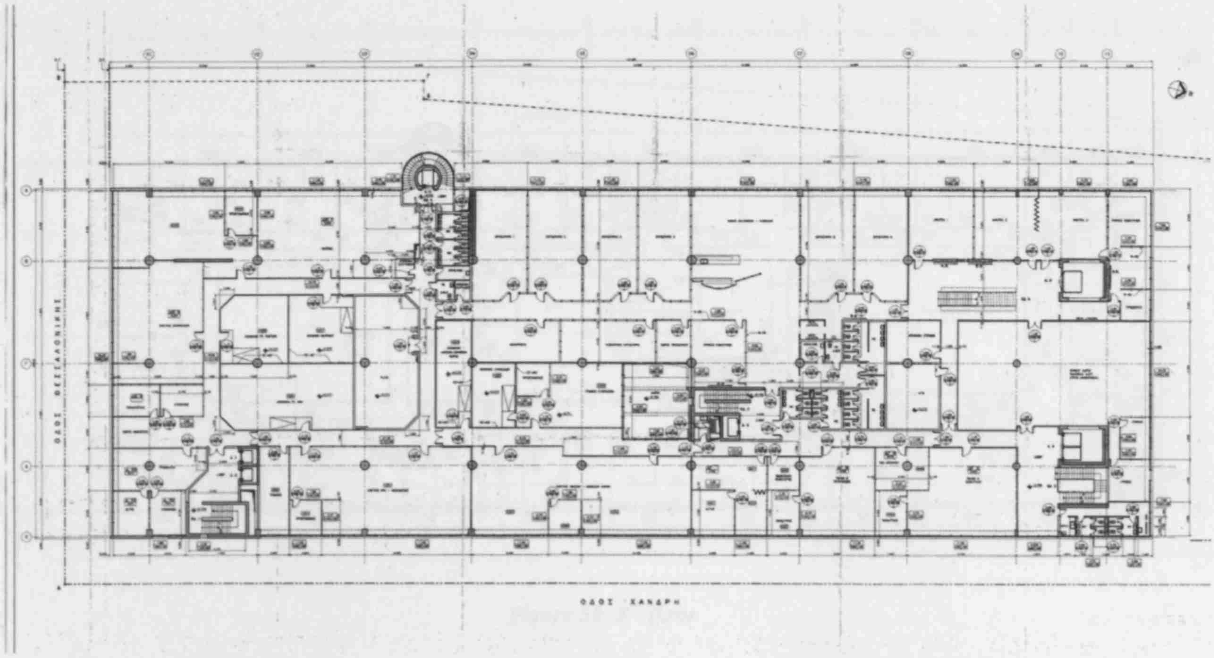


Figure 57: 1st floor

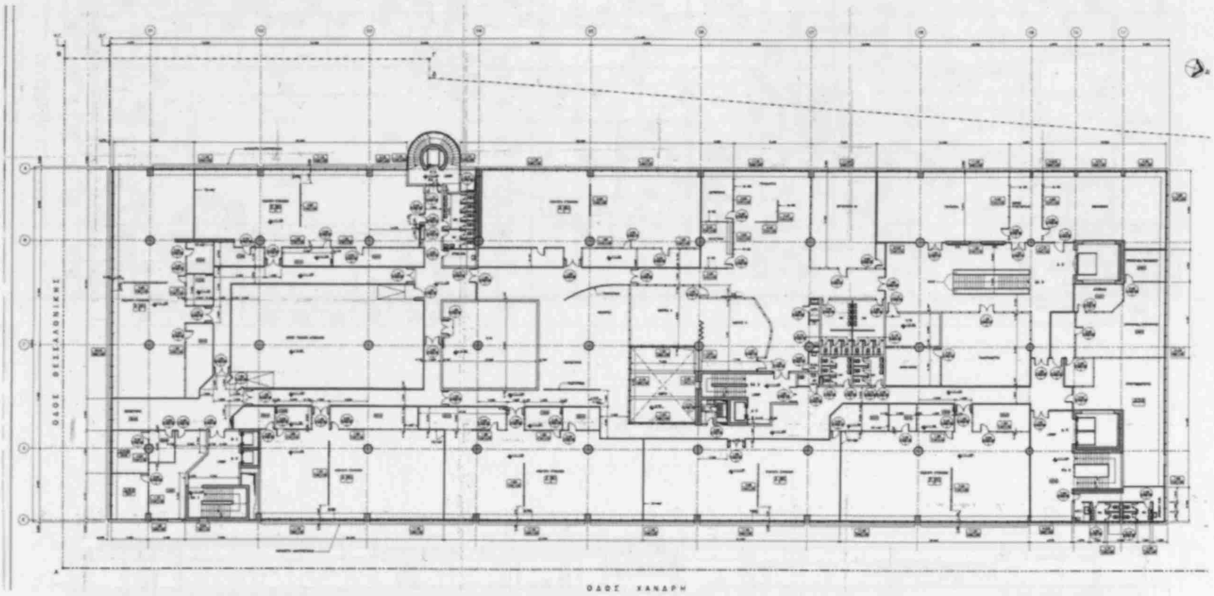


Figure 58: 2nd floor

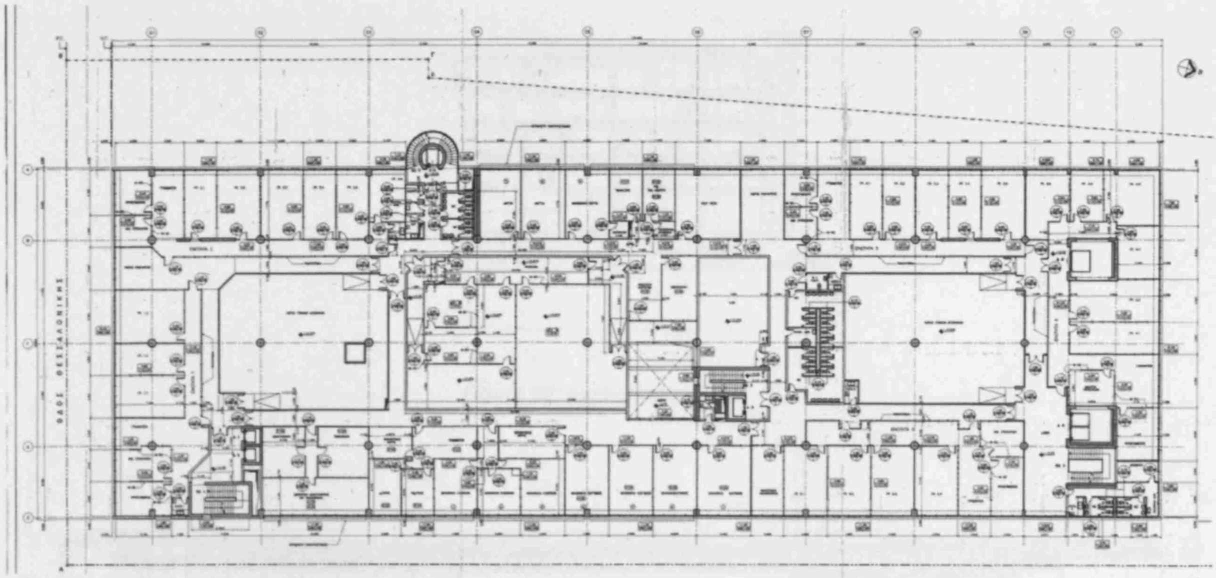


Figure 59: 3rd floor

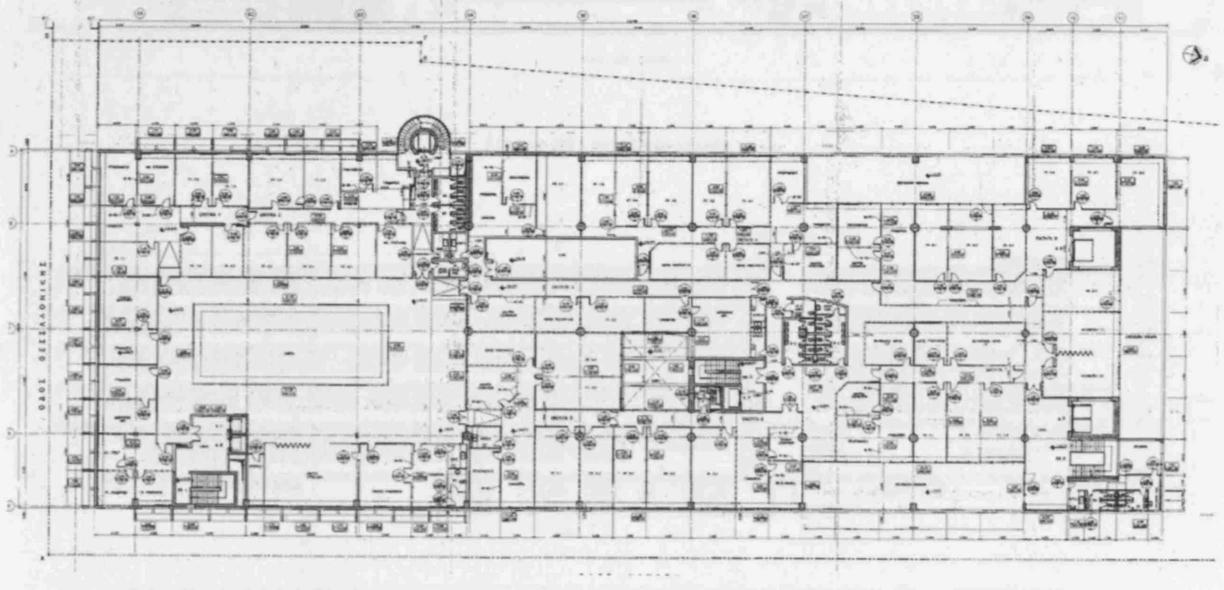


Figure 60: 4th floor

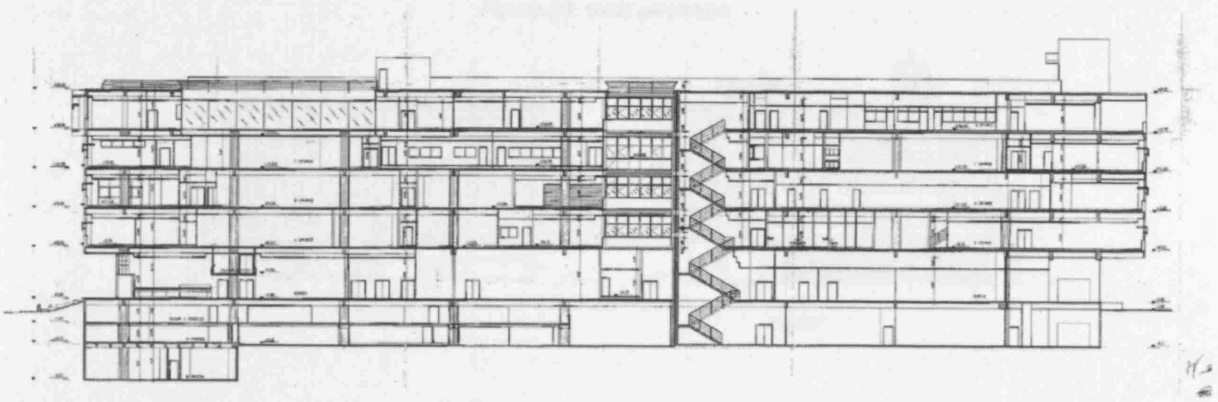


Figure 61: north-south section

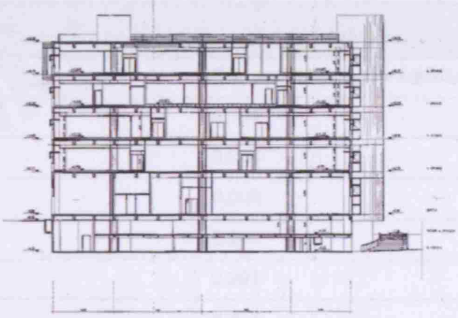


Figure 62: east-west section

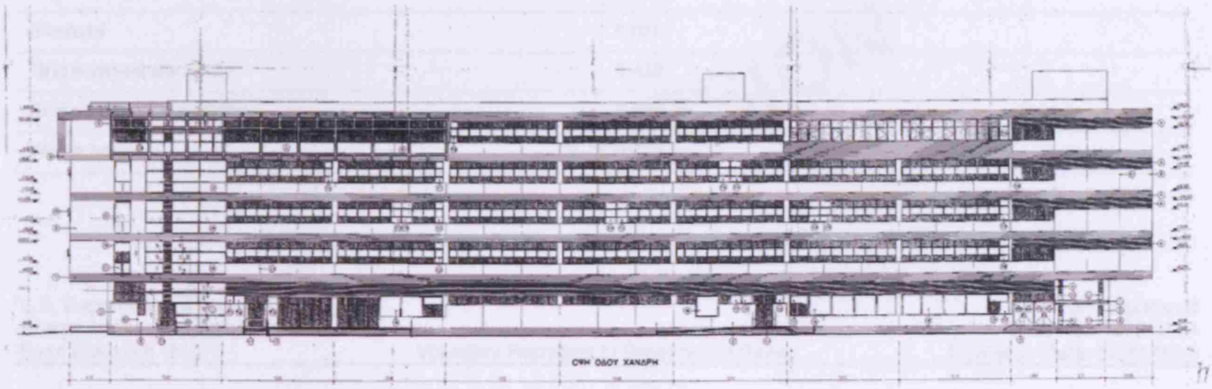


Figure 63: west elevation

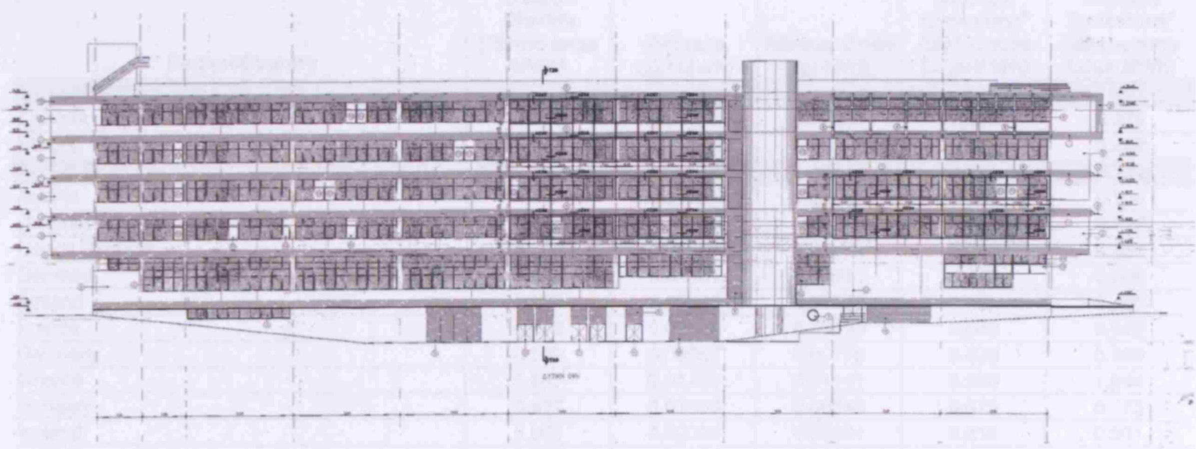


Figure 64: west elevation

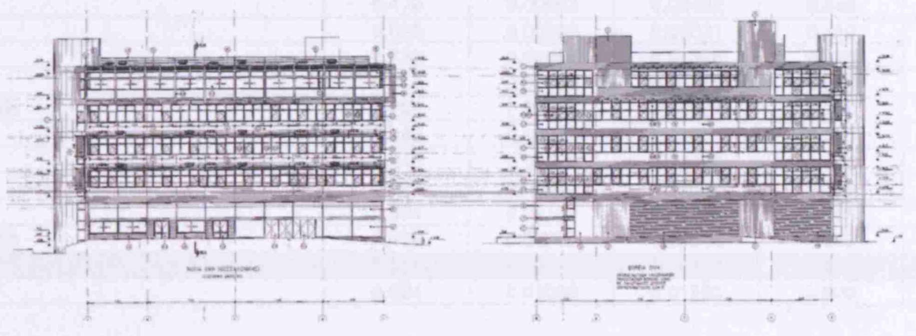


Figure 65: south and west elevations

Table 2 CO_2 emission factors

Fuel	CO_2 emission factor $kgCO_2/kWh$
Natural gas	0.194
LPG	0.234
Biogas	0.025
Oil	0.265
Coal	0.291
Anthracite	0.317
Smokeless fuel (inc. coke)	0.392
Dual fuel appliances (mineral + wood)	0.187
Biomass	0.025
Grid supplied electricity	0.422
Grid displaced electricity[1]	0.568
Waste heat[2]	0.018

Figure 66: CO_2 emission factors

U.S. Department of Energy
Energy Information Administration
Form EIA-1605 (2007) Voluntary Reporting of Greenhouse Gases

Form Approved
OMB No. 1905-0194
Expiration Date: 07/31/2010

F.3 Foreign Electricity Emission Factors, 1999-2002

Region/Country	Emission Inventory[a]			Emission Reductions	
	Carbon Dioxide (Metric tons/ MWh)	Methane (kg/ MWh)	Nitrous Oxide (kg/ MWh)	Avoided Emissions[b] (Metric tons CO_2e/MWh)	Indirect Emissions[c] (Metric tons CO_2e/MWh)
OECD North America					
Canada	0.223	0.00390	0.00351	0.802	0.876
Mexico	0.593	0.01676	0.00230	0.763	0.899
OECD Europe[d]	**0.387**	**0.00694**	**0.00505**	**0.694**	**0.749**
Austria	0.197	0.00377	0.00207	0.558	0.594
Belgium	0.289	0.00420	0.00275	0.682	0.716
Czech Republic	0.604	0.00783	0.01074	0.782	0.854
Denmark	0.358	0.01181	0.00831	0.475	0.506
Finland	0.239	0.00395	0.00348	0.451	0.468
France	0.083	0.00136	0.00093	0.849	0.912
Germany	0.539	0.00637	0.00779	0.829	0.869
Greece	0.887	0.01453	0.01141	0.900	1.044
Hungary	0.437	0.01009	0.00540	0.673	0.773
Iceland	0.001	0.00003	0.00001	0.315	0.331
Ireland	0.699	0.01623	0.00765	0.738	0.807
Italy	0.525	0.01773	0.00482	0.649	0.693
Luxembourg[e]	0.387	0.00694	0.00505	0.694	0.749
Netherlands	0.479	0.00998	0.00492	0.545	0.568
Norway	0.005	0.00003	0.00001	0.410	0.442
Poland	0.730	0.01084	0.01528	0.749	0.848
Portugal	0.511	0.01459	0.00711	0.690	0.755
Slovak Republic	0.297	0.00357	0.00324	0.706	0.750
Spain	0.443	0.00923	0.00631	0.790	0.865
Sweden	0.048	0.00092	0.00046	0.495	0.537
Switzerland	0.022	0.00030	0.00005	0.379	0.408
Turkey	0.584	0.01135	0.00628	0.786	0.973
United Kingdom	0.475	0.00793	0.00549	0.643	0.701
OECD Asia	**0.511**	**0.00787**	**0.00679**	**0.808**	**0.963**
Australia	0.924	0.01008	0.01290	0.900	1.096

Figure 67: electricity emission factors (US Department of energy)

Building type	Use	Density of occupation / person·m⁻²	Sensible heat gain / W·m⁻²			Latent heat gain / W·m⁻²	
			People	Lighting*	Equip't†	People	Other
Offices	General	12	6.7	8–12	15	5	—
		16	5	8–12	12	4	—
	City centre	6	13.5	8–12	25	10	—
		10	8	8–12	18	6	—
	Trading/dealing	5	16	12–15	40+	12	—
	Call centre floor	5	16	8–12	60	12	—
	Meeting/conference	3	27	10–20	5	20	—
	IT rack rooms	0	0	8–12	200	0	—

Figure 68: benchmark allowances for internal heat gains in typical buildings (CIBSE Guide A)

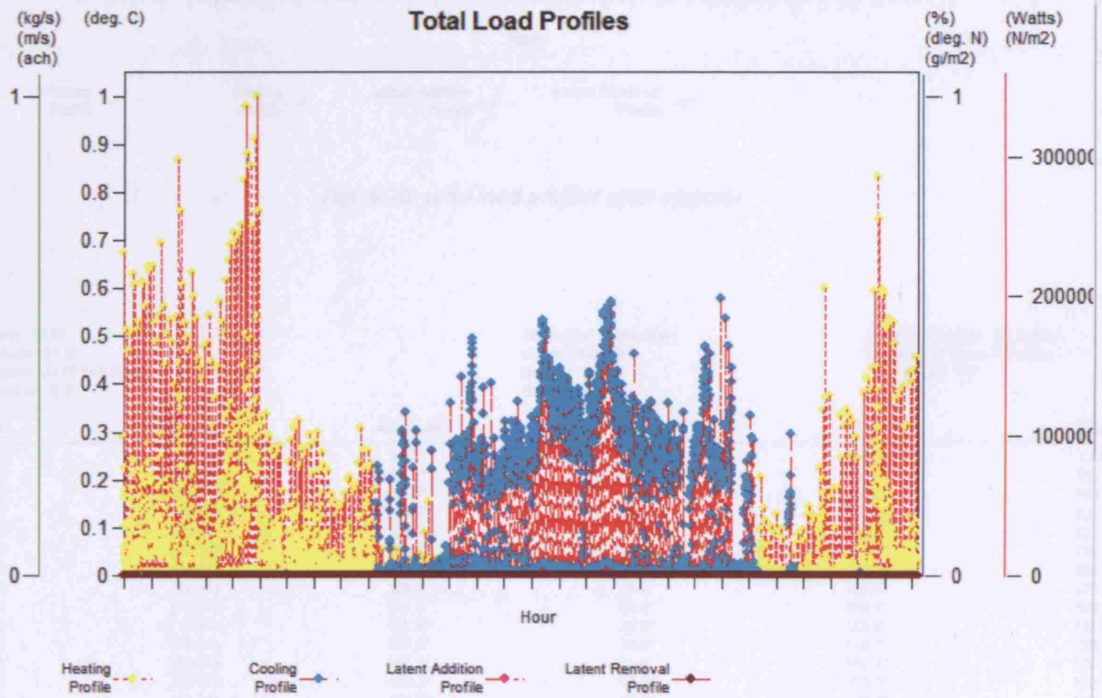


Figure 69: total load profiles before upgrade

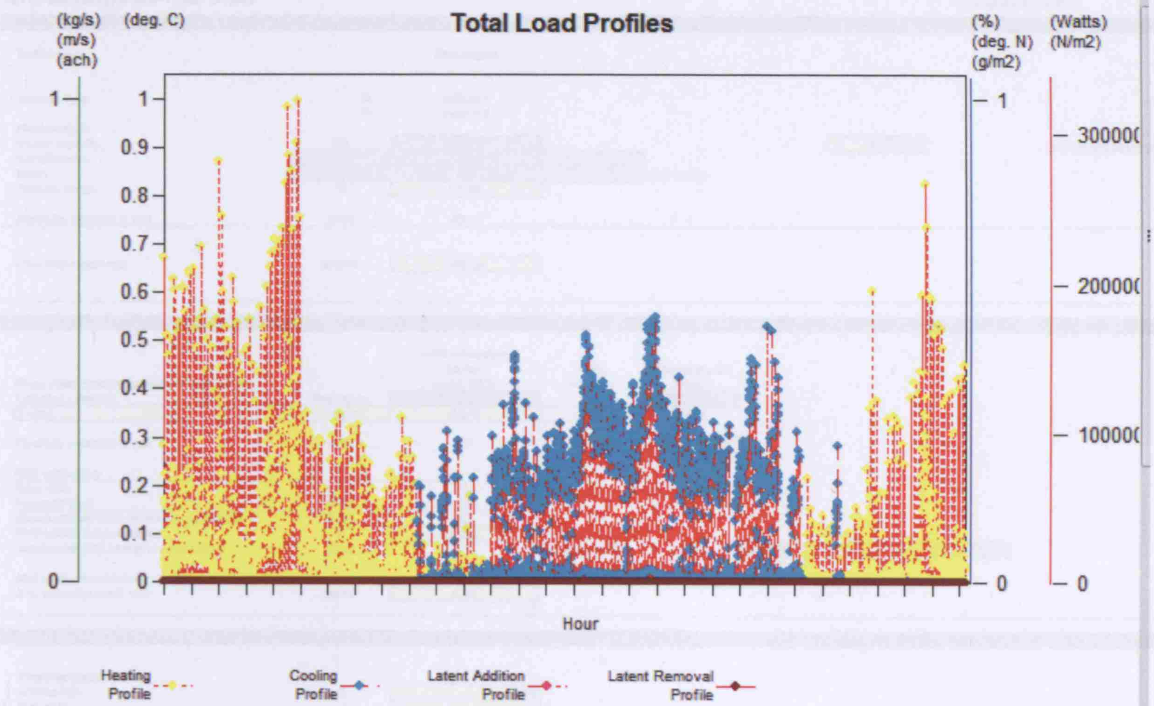


Figure 70: total load profiles after upgrade

Latitude: 37.8°
Longitude: 21.2°
Timezone: 30.0° [+2.0hrs]
Orientation: 0.0°

Date: 21st September
Julian Date: 264
Sunrise: 06:25
Sunset: 18:31

Local Correction: -28.3 mins
Equation of Time: 6.9 mins
Declination: 1.0°

Local	(Solar)	Aziumuth	Altitude	HSA	VSA
06:30	(06:01)	89.5°	0.9°	89.5°	61.6°
07:00	(06:31)	94.1°	6.9°	94.1°	120.7°
07:30	(07:01)	98.8°	12.8°	98.8°	124.1°
08:00	(07:31)	103.7°	18.6°	103.7°	125.3°
08:30	(08:01)	109.0°	24.2°	109.0°	125.9°
09:00	(08:31)	114.7°	29.7°	114.7°	126.2°
09:30	(09:01)	121.1°	35.0°	121.1°	126.4°
10:00	(09:31)	128.3°	39.9°	128.3°	126.6°
10:30	(10:01)	136.5°	44.2°	136.5°	126.7°
11:00	(10:31)	145.9°	48.0°	145.9°	126.7°
11:30	(11:01)	156.5°	50.8°	156.5°	126.8°
12:00	(11:31)	168.3°	52.6°	168.3°	126.8°
12:30	(12:01)	-179.3°	53.2°	-179.3°	126.8°
13:00	(12:31)	-166.9°	52.5°	-166.9°	126.8°
13:30	(13:01)	-155.2°	50.5°	-155.2°	126.8°
14:00	(13:31)	-144.7°	47.6°	-144.7°	126.7°
14:30	(14:01)	-135.5°	43.8°	-135.5°	126.7°
15:00	(14:31)	-127.4°	39.3°	-127.4°	126.6°
15:30	(15:01)	-120.3°	34.4°	-120.3°	126.4°
16:00	(15:31)	-114.0°	29.1°	-114.0°	126.2°
16:30	(16:01)	-108.4°	23.6°	-108.4°	125.8°
17:00	(16:31)	-103.2°	17.9°	-103.2°	125.2°
17:30	(17:01)	-98.3°	12.1°	-98.3°	123.9°
18:00	(17:31)	-93.6°	6.2°	-93.6°	119.8°
18:30	(18:01)	-89.0°	0.3°	-89.0°	14.0°

Figure 71: Sola data for 21st September (Solar tool)

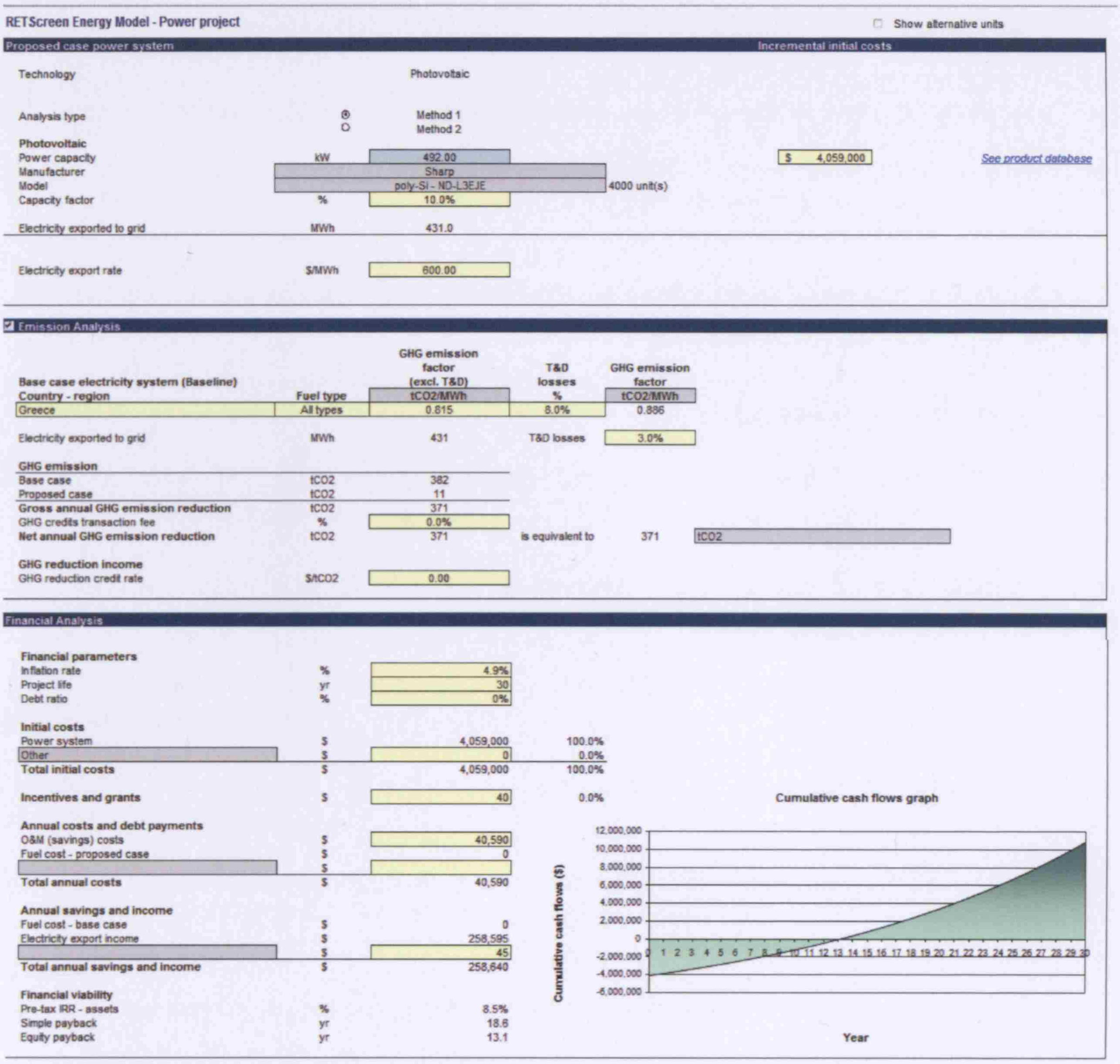


Figure 72: Retscreen data sheet for the estimation of the PVs (Retscreen)

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Discount factor	1	0.9533	0.9088	0.8663	0.8258	0.7873	0.7505	0.7154	0.6820	0.6502	0.6198	0.5908	0.5632	0.5369	0.5119	0.4879	0.4651	0.4434
Cost of PV	-1623600	147340	147340	147340	147340	147340	147340	147340	147340	147340	147340	147340	147340	147340	147340	147340	147340	147341
Discounted Cost	-1623600	140458	133897	127642	121680	115996	110578	105413	100489	95795	91320	87054	82988	79111	75416	71893	68535	65334

Figure 73: discount flow analysis of the payback time of the PV installation

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Figure 18: Google Earth

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Figure 24: personal archive

Figure 25: personal archive

Figure 26: Pleias LTD

Figure 27: Pleias LTD

Figure 28: HRREC

Figure 29: HRREC

Figure 30: HRREC

Figure 31: HRREC

Figure 32: Weather tool

Figure 33: Weather tool

Figure 34: Weather tool

Figure 35: Weather tool

Figure 36: Weather tool

Figure 37: NKUA

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Figure 39: Axima services

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Figure 41: TAS

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Figure 67: US department

Figure 68:CIBSE Guide A

Figure 69:TAS

Figure 70:TAS

Figure 71:Solar tool

Figure 72: Retscreen

List of abbreviations:

BEMS *Building Energy Management System*

CO_2 *Carbon dioxide*

COP *Coefficient of Performance*

EPBD *European Performance of Buildings Directive*

EU *European Union*

GHG *Greenhouse gas*

GSIS *General Secretariat for Information Systems*

HRREC *Hellenic Republic Real Estate Corporation*

HSA *Horizontal Shadow Angle*

Low-e *Low emissivity*

NKUA *National Kapodistrian University of Athens*

PV *Photovoltaic*

REVIVAL *Retrofitting for Environmental Viability Improvement of Valued Architectural Landmarks*

VSA *Vertical Shadow Angle*

Software used:

Adobe Photoshop CS3

Autodesk Autocad 2008

Ecotect 5.60

EDSL TAS

Microsoft Excel 2007

Microsoft Word 2007

Retscreen 4.0

Solar Tool

Weather Tool